



0054455

Department of Energy
Richland Operations Office
P.O. Box 550
Richland, Washington 99352

FEB 15 2001

01-GWVZ-013

Ms. Laura J. Cusack
Project Management Section Manager
Nuclear Waste Program
State of Washington
Department of Ecology
1315 W. Fourth Avenue
Kennewick, Washington 99336

RECEIVED
FEB 27 2001
EDMC

Dear Ms. Cusack:

**LIQUID EFFLUENT RETENTION FACILITY (LERF) MONITORING ALTERNATIVE
EVALUATIONS AND RESULTANT PROPOSED MULTI-FACETED MONITORING
SYSTEM**

As you are aware, on January 2, 2001, the U.S. Department of Energy, Richland Operations Office (RL), determined that monitoring well 299-E35-2 is no longer capable of producing a representative groundwater sample for monitoring the LERF. As a result of this, RL has evaluated a large suite of potential alternate monitoring systems. There have been numerous meetings with the State of Washington Department of Ecology (Ecology) to discuss these potential monitoring options. Attachment 1 contains a detailed evaluation of several potential monitoring technologies applicable to the LERF, and a formal response to Ecology's July 21, 2000, correspondence that evaluates several potential vadose zone and leak-detection technologies, in addition to discussions on the following:

- Problems with retrofitting existing double-composite lined facilities with vadose zone monitoring devices,
- differences between leak detection and vadose zone monitoring technologies, data quality objectives related to the required precision and accuracy for a LERF monitoring system,
- differences in construction/operation between a municipal waste landfill and a surface-water impoundment facility, and
- performance differences between single-lined and composite double-lined systems (with a leachate collection system).

In response to the Ecology letter to Michael Thompson and Kevin Leary, RL, from Dib Goswami and Fred Jamison, "Liquid Effluent Retention Facility (LERF) Unsaturated Zone Monitoring Alternatives Evaluation, Suspension of Groundwater Monitoring Statistical Evaluation Requirements, LERF RCRA Permit Modification, and Leachate Monitoring Performance Criteria," dated January 24, 2001, RL is providing the following information:

54419

FEB 15 2001

- Leachate laboratory data (Attachment 2),
- double-liner performance evaluation letter report (Attachment 3),
- liner collection system design schematics (Attachment 4) that are from diagrams 4-16 through 4-19 found in the Resource Conservation and Recovery Act permit,
- GSE Hyperflex manufacturer information (Attachment 5), and
- two articles on High-Density Polyethylene (HDPE) liners that support the 50 year liner design life estimate (Attachment 6).

The HDPE liner system design life is approximately 50 years; based upon a January 3, 2001, conversation between Mark Bowman (Fluor Hanford, Inc.) and James Gussman (GSE Hyperflex, 1-800-435-2008). The extended life expectancy of the liner is primarily due to the HDPE being protected from ultraviolet degradation with each LERF cover.

After a careful evaluation of the several monitoring technologies discussed in Attachment 1, RL proposes the following for the LERF:

1. Develop a vadose zone model and generate a preliminary risk assessment.
2. Conduct a leachate monitoring program of both leachate quality and quantity for two years on a quarterly basis. Once a baseline is established, go to bi-annual sampling. This action will also include minimizing the amount of leachate retained in the collection sump by automating the system with a pressure transducer, thereby minimizing leachate head above the secondary containment system.
3. Evaluate the feasibility of deploying new, high technology flow-meters in order to reduce the error and increase the precision of conducting a mass balance of the LERF influent and effluent. This approach will only be deployed if the initial feasibility study demonstrates that that new meters will allow the detection of a leak that is smaller than other technologies (e.g., High Resolution Resistivity [HRR]). Note that the mining industry is currently using a "mass-balance" approach with single-lined, uncovered heap-leach tailings ponds, some of which are several hundred acres in size.
4. Field test HRR at a bench-scale level. If the test is successful, evaluate the feasibility of deploying this technology at LERF. If the field test is a failure, RL will continue to search for any new technologies that may have potential deployment capabilities for the LERF. Note that the precision/error of both HRR and mass balance methodologies can be converted into the ability to detect minimum gallons of leakage through the secondary containment system. This, in turn, can be incorporated into the vadose zone model. Data from the model should be able to project the extent of contaminant transport in the vadose zone and the resultant preliminary risk to human health and the environment. The feasibility of applying a mass-balance approach, or HRR to the LERF, will be conducted during the two-year period of establishing a leachate quality and quantity baseline.

FEB 15 2001

Ms. Laura J. Cusack
01-GWVZ-013

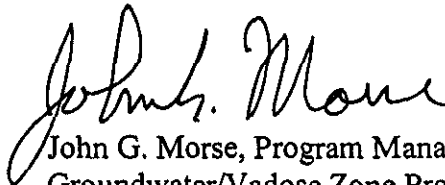
-3-

Since RL will be applying for final status, WAC 173-303-645 contains the final status requirements for LERF and thereby replaces WAC 173-303-655(6).

RL is proposing a meeting with Ecology on March 14, 2001, to discuss the multi-faceted monitoring system proposed above, as well as a discussion on Ecology's Data Quality Objectives for a LERF alternate monitoring program. Once a monitoring system is agreed upon by both Ecology and RL, a compliance schedule can then be formulated by RL.

If you want to discuss this matter further or require additional information, please contact Marvin J. Furman or Michael Thompson, Groundwater Vadose Zone Project, at (509) 373-9630 and (509) 373-0750 respectively, or Kevin Leary, Waste Management Division, at (509) 373-7285.

Sincerely,



John G. Morse, Program Manager
Groundwater/Vadose Zone Project

GWVZ:MJF

Attachments

cc w/attachs:

M. L. Blazek, Oregon Energy
J. Caggiano, Ecology
K. A. Conaway, Ecology
D. N. Goswami, Ecology
A. D. Huckaby, Ecology
F. C. Jamison, Ecology
D. R. Sherwood, EPA
T. M. Martin, HAB
Administrative Record

cc w/o attachs:

M. W. Bowman, FHI
J. G. Granger, FHI
D. K. Smith, FHI
R. W. Szelmezcza, FHI
J. D. Williams, FHI
J. S. Fruchter, PNNL
S. P. Luttrell, PNNL
M. W. Sweeney, PNNL

ATTACHMENT 1

EVALUATION OF POTENTIAL MONITORING TECHNOLOGIES FOR THE LERF

The Department of Ecology issued a letter on July 21, 2000 from Jean Wallace, Waste Management Project Manager to Michael Thompson, U.S. Department of Energy. Ecology stated that workshop participation alone (conducted on May 31, 2000) would not be sufficient to satisfy Ecology's September 22, 1999 letter requirement. Additionally, Ecology questioned the pursuit of the Demonstration (WAC 173-303-650(2)(b)) instead of the alternatives described in Environmental Monitoring Alternatives for the Liquid Effluent Retention Facility. Additionally, Ecology asked RL for additional information on the monitoring alternatives. However, prior to presenting this material, several points need to be clarified.

First, there are several major challenges in order to retrofit the existing Liquid Effluent Retention Facility (LERF) with vadose zone monitoring equipment and applying point-measurement vadose zone monitoring as a method of leak-detection. The majority of existing vadose monitoring technologies are applied to primarily measure either site specific soil moisture movement and/or collect "representative" soil-pore water samples for monitoring potential unsaturated zone contaminant transport. In general, facility vadose zone monitoring locations are selected as prototypes to be used as a representation of an entire area and/or facility. In contrast, liner leak detection generally requires a much higher density of vadose zone monitoring equipment be selectively installed in strategic areas below the liner (e.g., along seams and the deeper portions of the liner if the facility is a retention basin) during liner construction or the application of geophysics that may have limited resolution. Furthermore, retrofitting and installing vadose zone monitoring devices along the seams and deeper portions of the composite, double-lined system in an existing facility would severely impact the liner integrity.

Since the objectives of vadose monitoring and leak detection are often different, the majority of vadose zone monitoring technologies are not suited for leak detection. The accuracy and precision of the selected method(s) (vadose zone monitoring and/or leak detection) is entirely dependent upon the precision and error required as established during the formulation of your data quality objectives. In turn, the data quality objectives should be directly related to the estimated resultant risk derived from a risk assessment.

In addition, Ecology is probably aware that there have been incidents where municipal solid waste landfill liners have failed and leachate collection systems have not collected all the leachate resulting in groundwater contamination. However, there needs to be some clarification regarding the circumstances of municipal solid waste landfill liner failure. First off, these cells were likely single lined cells with just a HDPE liner as opposed to the composite (HDPE, bentonite and geotextile layers), double containment system (with leachate collection system) found at LERF. Secondly, tears in the landfill liners likely occurred from heavy equipment moving daily across the landfill cell moving and compacting refuse and applying daily covers. This is in complete contrast to the construction and operation of the LERF facility.

Liner longevity is based upon composition of liner materials, the actual construction of the liner and precautions taken during construction to prevent tears during liner installation, quality of the

wastewater and the resultant chemical interactions affecting the longevity of the liner, and the actual life expectancy requirements of the facility to treat wastewater. See Attachment 5 for liner manufacturer information. Also note that one of the primary factors affecting liner longevity (in addition to influent chemistry) is ultraviolet light degradation of the liner. Since each of the 3 retention basins have covers, the projected liner-life expectancy of the liner is actually greater than under normal "uncovered" circumstances.

In a recent article (p. 96) in February 2001 *Civil Engineering Journal*, by Robert M. Koerner, PhD and P. E. (Professor of Civil Engineering, Drexel University and Director of Geosynthetic Research Institute, Philadelphia, PA) entitled "Do We Need Monitoring Wells at Double-Lined Landfills," the following key points were made:

- Monitoring wells are excessive in light of the performance of double-lined geosynthetic landfill liners
- Results from analyzing monitoring data from 91 landfills (with 287 cells), the average post-closure leakage rates were less than 10 gal/acre/day (less than 100 liters/hectare/day)
- Why do we still use monitoring wells surrounding double-lined landfills to detect incredibly low values of leakage that "might" get through the secondary liner system?
- If a double-lined systems is deployed, monitoring wells should only be used if a leakage rate exceeds a preset value specific to the site in question

The following is a summary of technologies that Ecology requested that DOE evaluate further:

1. **Electrical Resistivity Tomography (ERT)** as a geophysical technique for leak detection does not appear to have been considered for monitoring at depth. It is recognized that the side wall slope and basin would make electrode installation difficult near the surface and in particular, directly beneath the LERF. The discussion of placement of electrodes at a "distance sufficient to limit disruption of the basins" was not described in sufficient detail for Ecology to understand spatial limitations. Therefore, it is requested that a detailed description of electrode placement satisfying basin disruption limitations, as well as noise reduction limitations be provided. In addition, it is requested that a graduated depth installation of ERT electrodes be considered.

DOE Response: *Electrical Resistivity Tomography (ERT)*--In response to Ecology letter, the noise study to determine if the electrodes could be placed around the perimeter of the LERF would cost ~\$ 60 K. A rough order cost estimate for electrode installation would \$ 1,000 K. (Does not include equipment costs.)

Costs: Approximately 1.1 million for installation

Pro's: May provide a method of leak detection below the secondary containment system

Con's: Expensive; technology not proven for this application; site-specific noise levels may be too great to apply technology (e.g., what level of resolution can we obtain without disrupting the basin

and jeopardize the structural integrity of each retention basin?); precision may not be great enough for the "developing criteria" that may be derived from a future, streamlined DQO process; movement of water does not necessarily equate to contaminant migration, especially in a double-lined system that functions as a two-phase reverse osmosis system and adsorbs contaminants onto the bentonite portion of the liner.

Average annual quantities of leachate generated at the LERF are well within the acceptable diffusion rates for the HDPE liner as provided by the manufacturer (see Attachment 5). Furthermore, the life expectancy of the liner is 50 years (per a telephone conversation between Mark Bowman-FHI and James Gussman of *GSE Lining Technologies* on January 3, 2001 at 1-800-435-2008). A November 18th, 1998 letter report by Mark W. Bowman (of FHI) provides data that indicate a seasonal correlation between quantity of leachate generation and the relationship with liner expansion and subsequent increased diffusion (Attachment 3). If the increased leachate production observed in the summer is due to induced thermal heating of the upper liner due to both the heating of the waste water as well as thermal heating of the near-surface liner, then one would expect little or no leachate permeation through the lower liner since the lower liner is well below the surface and seasonal thermal changes have little or no impact on its physical and or chemical composition. Furthermore, laboratory results from two sampling events (Attachment 2) of the leachate and results presented in Bowman's report (Attachment 3) clearly illustrate the process of passive selective diffusion. Mr. Bowman concluded that the maximum leachate rate per area was about 26 gallons/acre-day. This is still considerably less than the 2100 gallons/acre-day which is the "action leak rate" in the RCRA permit.

2. **Geophysical logging techniques for moisture detection** using inclined drilling installation techniques do not appear to have been considered. Inclined drilling techniques have been successfully demonstrated at the Hanford Site. Therefore, it is requested that a detailed description of inclined drilling for moisture detection purposes be provided.

DOE Response: Geophysical Logging for Moisture Detection--Two different concepts are being considered. The first design, using inclined drilling, would place the bore hole at a depth under the basin. The specific depth of boreholes under the basin will be an important factor since geophysical logging techniques have very limited sensitivity.

The second design would use directional or horizontal boreholes under each basin. The design under consideration would be three horizontal boreholes under each basin. The boreholes could be placed in the sub-grade under the secondary composite liner (see also Excitation of Mass and High Resolution Resistivity techniques below).

Inclined Cost a) \$ TBD

Horizontal Costs b) \$1.8 million (Installation of only three horizontal bore holes per basin.)

Pros: Ecology is familiar with the geophysical logging technique using inclined drilling installation techniques.

Cons: The sensitivity of the logging is limited to 2 to 6 inches from the borehole. Potentially the inclined drilling techniques could place the borehole at considerable depth under the basins. Coupled with the sensitivity associated with GTL, this could mean a leak would have to travel substantial depth to be detected (inclined drilling installation techniques.) Additionally, the argument of adequate coverage for selecting the numbers of and the locations for the boreholes in order to intercept a potential leak from the LERF basins would be difficult and impracticable. In other words, since this type of geophysical logging provides point measurements and if the objective of the monitoring is leak detection, the number of sampling points and the associated costs would be astronomical. On the other end of the spectrum, even a few boreholes would still be quite expensive. This limited coverage would, albeit be a "vadose monitoring system," provide such ineffective coverage that the monitoring system would be considered poor at best. In addition, there may be potential problems of adversely impacting the structural integrity of the basin sidewalls from the inclined or horizontal drilling.

3. **Soil-gas monitoring(tracer gas techniques)** for waste constituents does not appear to have been considered to occur at depth. Ecology concurs with the report's recommendation to use soil-gas sampling in conjunction with either shear-wave seismic tomography or a system based on the principle of excitation of mass. Therefore, it is requested that a detailed description of soil gas boreholes/cone penetrometers with a graduated depth of installation be considered.

DOE Response: Soil-Gas Monitoring-- In this process, gaseous waste constituents (that is, ammonia) will diffuse from a leak into the soil as a vapor and act as tracers to provide an indication of the failure of the secondary containment at the LERF. PNNL has conducted some research to evaluate the potential of using tritium as a tracer. However, results indicate that it will not be detected in soil gas (in low enough concentrations to be useful). However, PNNL found that Helium-3 will be detected if sufficient time elapsed from the time of release (to the environment) to allow a sufficient quantity of helium-3 to be produced from decay. Unfortunately, this is on the order of years, not weeks or months, as would be required for an application to LERF. Preliminary design would be the installation of 18 soil gas bore holes screened off at different depths. [Six bore holes per basin, (three north and three south of each basin.)] Estimated drilling costs would be \$ 250K. There is a new technology called partitioning inter-well tracer testing (PITT) that is a different application of soil-gas methodology that is discussed in section 4 of this attachment .

Cost: \$ 750 K +

Pros: Tracers are capable of detecting gaseous waste constituents only under certain conditions. If these conditions are met and the use of soil-gas monitoring is used, the boreholes could also be designed for multi-purpose monitoring. It may be possible to construct the boreholes to monitor for soil moisture (neutron access tubes) with soil gas sampling ports and an open hole at the end of the neutron access tube to permit direct soil sampling to evaluate the contaminant transport of gaseous as well as non-gaseous COC's.

Cons: Tracers are not capable of detecting non-gaseous waste constituents (for example, metals.) Also, adequate coverage for selecting the numbers of and the locations for the soil gas sampling ports (and/or boreholes) in order to intercept a potential leak from the LERF basins would be difficult and very costly. Because of the numerous uncertainties associated with deploying soil-gas leak-detection technology to the LERF, the ability to evaluate the technical and physical capabilities of monitoring soil gas at depth is not known at this time.

4. **Designing monitoring system which tracks moisture and waste-specific contaminants through the vadose zone beneath and/or down-gradient of the LERF.** Ecology recognizes the physical limitations associated with monitoring directly beneath the unit (i.e., with lysimeters or an equivalent soil-liquid pore monitoring system). Therefore, it is requested that a description of an environmental monitoring system capable of tracking moisture and water-specific contaminants through the vadose zone be described in relation to satisfying the intent of WAC 173-303-655(6) as replaced by WAC 173-303-645 (final status requirements of the LERF).

DOE Response: DOE and PNNL evaluated the feasibility (technical and financial) of deploying various existing and new technologies that may have the capability of tracking moisture and/or contaminants through the vadose zone. However, there are several major challenges to overcome and include such things as retrofitting the Liquid Effluent Retention facilities with vadose zone monitoring equipment, field testing innovative technologies to evaluate the feasibility and applicability to the LERF, and applying point-measurement vadose zone monitoring as a method of leak-detection. The following are a summary of technologies, both existing and experimental, that may have some applicability for monitoring leaks from the LERF basins:

a. *Excitation of Mass (EOM)*--The excitation of mass, a method of leak detection, relies on establishing a potential field inside the storage basin. Testing consists of measuring the potential field inside or outside the basins for potential leakage. A *potential-leak* is a potential field that appears outside the facility and is generated by the charge impressed inside the basins. Tears in the basin liners, or other preferred pathways that bypass the protective barriers, generally cause these "potential-leaks" and their associated fields.

Cost: \$ 700 K

Pros: Ecology stated they could use their enforcement discretion to accept a less-than-compliant system to meet the intent of WAC 173-303-655(6) as replaced by WAC 173-303-645 (final status requirements of the LERF).

Cons: A leak detection system is not capable of monitoring vadose for contaminants. EOM is not a mature and robust engineering system.

b. *High Resolution Resistivity (HRR)*—The High Resolution Resistivity is a geophysical tool that can be used to detect sub-surface moisture. PNNL performed a very small-scale study during the Spring of 2000. At present, there are plans to field-test the technology in 2001 to evaluate moisture/leak detection and the associated resolution of this technology. HRR can be

applied as both a surface geophysical survey or in the sub-surface down-hole in cased borehole. For surface applications at LERF, several two foot long probes would be permanently installed around each of the three LERF basins with one probe used as a transmitting probe for the electrical impulse and the remaining probes used as receivers. Mr. Jim Fink, out of Tucson, AZ, at 520-647-3315 of the firm *Hydrogeophysics*, is the individual who brought the technology to Hanford. *Hydrogeophysics* website is www.hydrogeophysics.com.

Cost: \$30 K/basin (\$90 K total) and an annual cost of \$20 K annual costs for technical support from *Hydrogeophysics* based on a quarterly monitoring schedule. If the down-hole methodology had to be used, there would be a cost of approximately \$200 K per hole with the number of holes dependent upon equipment resolution.

Pros: This is a relatively new technique that may have some promise for leak detection applicable to LERF. According to Mr. Fink, this technology has been successfully deployed at mine tailing ponds throughout the Western U. S. and was recently deployed to evaluate leakage from a single-lined power-company retention pond located near Tucson, AZ. Deployment at the LERF will be dependent upon future small-scale field tests.

Cons: The technology is unproven at the LERF. Initial small-scale tests conducted by PNNL indicate that applying HRR as surface geophysical tool used for leak detection at LERF may present some challenges. There is a possibility that new boreholes would have to be drilled adjacent to LERF in order to lower the tool down-hole for cross-hole tomography. Drilling new boreholes is expensive and the resolution for leak detection is unknown at this time. For example, what is the minimum size leak below the secondary containment system at the LERF that can be detected using either surface or down-hole HRR technology ?

c. **Partitioning Inter-well Tracer Testing (PITT)**—PITT is a different application of soil-gas monitoring methods. It is a field-proven method in detecting and quantifying vadose zone soil moisture. The technology integrates over a large volume, eliminating the need for large well arrays that often fail to achieve a representative sampling of the subsurface. The vadose zone underneath the facility would be swept by an air-advection flow-field (similar to the soil vapor extraction remediation technology) into which tracer gases are injected and the extraction wells then sampled. The resulting data may provide a means of leak detection, leak quantification, and an indication of leak location. Potentially, a conservative volatile tracer could be added to the LERF liquid to provide an additional mechanism for leak detection for the upper containment system. Several field demonstrations will be performed this fiscal year. One such project is the use of a partitioning tracer methodology as applied to Hanford tank leak detection and leak quantification.

Cost: TBD

Pros: The partitioning tracer methodology is an established technique for oil, NAPL, and moisture measurement in the subsurface. This technique has proven to be robust relative to subsurface heterogeneities and integrates over a large volume. Because it relies on physio-

chemical methods, it is not subject to the same interferences that geophysical methods are subject to. The basic principle of the technique decreases the likelihood of false positives and false negatives with respect to leak detection. Additionally, the technique can provide an indication of leak location and, depending on the design and operation of the actual system, information could be provided regarding the downward migration of a leak.

Cons: The partitioning tracer methodology has not been used as a leak detection technique and is unproven at the LERF. Wells or cone penetrometer bore-holes would need to be installed plus a vapor extraction system that would include air and tracer injection manifolds and extracted air-monitoring instrumentation. The large scale of the LERF is a concern for operating the air- advection flow-field and the volume of tracer required. In addition, because the geology under the LERF is highly heterogeneous and the distance between injection and collection bore holes would be great (e.g., 300 feet), there may be problems with gas-flow injection and subsequent recovery. In addition, even though a conservative volatile tracer would be selected, there is still the potential of reactions with both the HDPE liner and underlying bentonite clay layer. The unknown leak detection and quantification values for LERF are also a concern. The number of boreholes required cannot be determined until the characterization effort is completed and the design work is done based upon the characterization. Because of all of these constraints, this method would likely be expensive to implement.

5. Leachate Monitoring--Use the leachate collection system to monitor primary containment performance as a simplified form of vadose zone monitoring. Sample analysis of leachate collected on top of the secondary liner and the quantity of leachate generated can be used to demonstrate integrity of the primary liner. This would require a series of corrective actions to be taken if diffused leachate volumes increased significantly or leachate quality significantly deteriorated. If sampling confirms that the primary liner is intact through leachate quality and quantity, there is no reason to suspect waste migration into and out of the secondary liner into the underlying vadose zone.

Cost: TBD

Pros: This provides a more proactive approach than waiting until contamination is detected in groundwater and provides in essence a composite leachate sample taken from the zone below the basin and the primary containment system. Leachate monitoring and control will provide an early warning detection and the opportunity to implement a whole suite of potential corrective actions (if necessary). Corrective actions include such things as liner repair and/or construction completion of the fourth unfinished basin.

However, the cost to finish the fourth basin would be about ten million dollars. This is a very expensive corrective action, however, if future treatment volume demands increase, construction of a fourth basin may be necessary. If this action comes to fruition, the installation of such things as: Time Domain Reflectometry (TDR) probes (for measuring soil moisture), heat dissipation probes (for measuring soil matric potentials), horizontal neutron access tubes

(for measuring soil moisture), and advanced soil sampling lysimeter (for direct sampling of soil-pore water) , could be installed in areas where leaks are most likely to occur (e.g., along the seams and the deepest point of the basin).

Cons: The current permit writers are resistive to utilizing leachate monitoring as the only method of monitoring.

ATTACHMENT 2

LERF LEACHATE LABORATORY DATA

LERF Basin Leachate

STREAM	Units	Basin 42 Leachate 10/2000	Basin 42 Leachate 9/1998	Basin 43 Leachate 9/1998	Basin 44 Leachate 10/2000
pH		7.14			8.07
Aluminum	ug/L	2.73E+01	2.07E+01	4.21E+00	3.88E+01
Ammonia (as N)	ug/L	7.54E+02	Not Detected	Not Detected	Not Detected
Antimony	ug/L	1.20E+00	1.89E+01	2.29E+01	1.89E+00
Arsenic	ug/L	5.36E+00	5.10E+00	7.90E+00	1.38E+01
Cadmium	ug/L	2.84E-01	4.00E-01	4.00E-01	Not Detected
Calcium	ug/L	Not Detected	Not Analyzed	Not Analyzed	Not Detected
Chromium	ug/L	Not Detected	8.00E-01	8.00E-01	Not Detected
Copper	ug/L	5.85E+01	5.70E+01	6.40E+01	1.59E+01
Cyanide	ug/L	Not Detected	Not Analyzed	Not Analyzed	Not Detected
Iron	ug/L	4.18E+01	Not Analyzed	Not Analyzed	7.27E+01
Lead	ug/L	4.80E+01	3.14E+01	5.17E+01	1.31E+01
Magnesium	ug/L	2.21E+04	8.69E+01	5.59E+01	1.19E+04
Manganese	ug/L	6.67E+01	Not Analyzed	Not Analyzed	9.02E+00
Mercury	ug/L	Not Detected	Not Detected	Not Detected	Not Detected
Nickel	ug/L	1.93E+03	2.27E+03	1.39E+03	1.86E+03
Potassium	ug/L	1.24E+04	Not Analyzed	Not Analyzed	5.33E+03
Selenium	ug/L	Not Detected	Not Detected	2.70E+00	5.91E-01
Silicon	ug/L	1.36E+04	Not Analyzed	Not Analyzed	1.07E+04
Silver	ug/L	Not Detected	Not Detected	Not Detected	Not Detected
Sodium	ug/L	8.19E+04	Not Analyzed	Not Analyzed	7.61E+04
Uranium	ug/L	1.07E+00	2.00E+00	4.60E+00	6.43E+00
Zinc	ug/L	1.32E+01	1.72E+01	3.13E+01	0.00E+00
Chloride	ug/L	1.94E+04	2.56E+04	2.21E+04	1.73E+04
Fluoride	ug/L	Not Detected	Not Detected	Not Detected	3.50E+02
Nitrate (as N)	ug/L	1.11E+05	1.13E+05	4.85E+04	4.63E+03
Nitrite (as N)	ug/L	Not Detected	Not Detected	Not Detected	Not Detected
Phosphate	ug/L	Not Detected	Not Detected	Not Detected	2.36E+03
Sulfate	ug/L	8.97E+04	1.10E+05	1.02E+05	1.12E+05
Total dissolved solids	mg/l	9.39E-01	Not Analyzed	Not Analyzed	4.25E+02
Total organic carbon	ug/L	5.41E+03	Not Analyzed	Not Analyzed	5.27E+03
Total suspended solids	mg/l	Not Detected	Not Analyzed	Not Analyzed	4.00E+02
1-Butanol	ug/L	Not Detected	Not Analyzed	Not Analyzed	Not Detected
2-Butanone	ug/L	Not Detected	Not Analyzed	Not Analyzed	Not Detected
2-Butoxyethanol	ug/L	Not Detected	Not Analyzed	Not Analyzed	Not Detected
2-Hexanone	ug/L	Not Detected	Not Analyzed	Not Analyzed	Not Detected
2-Pentanone	ug/L	Not Detected	Not Analyzed	Not Analyzed	Not Detected
Acetone	ug/L	Not Detected	Not Analyzed	Not Analyzed	Not Detected
Acetophenone	ug/L	Not Detected	Not Analyzed	Not Analyzed	Not Detected
Benzyl alcohol	ug/L	Not Detected	Not Analyzed	Not Analyzed	Not Detected
N-nitrosodimethylamine	ug/L	Not Detected	Not Analyzed	Not Analyzed	Not Detected
Tetrahydrofuran	ug/L	Not Detected	Not Analyzed	Not Analyzed	Not Detected
Tri-n-butylphosphate	ug/L	Not Detected	Not Analyzed	Not Analyzed	Not Detected
Methylene Chloride	ug/L	9.00E-01	Not Analyzed	Not Analyzed	7.00E-01
Americium-241	pCi/L	Not Detected	Not Analyzed	Not Analyzed	Not Detected
Carbon-14	pCi/L	Not Detected	Not Analyzed	Not Analyzed	Not Detected
Cobalt-60	pCi/L	Not Detected	Not Detected	Not Detected	Not Detected
Cesium-134	pCi/L	Not Detected	Not Detected	Not Detected	Not Detected
Cesium-137	pCi/L	Not Detected	Not Detected	Not Detected	Not Detected
Tritium	pCi/L	1.30E+06	Not Analyzed	Not Analyzed	6.50E+05
Neptunium-237	pCi/L	1.70E-01	Not Analyzed	Not Analyzed	2.00E-01
Plutonium-238	pCi/L	3.70E-01	Not Analyzed	Not Analyzed	2.30E-01
Plutonium-239/240	pCi/L	1.80E-01	Not Analyzed	Not Analyzed	2.20E-01
Strontium-90	pCi/L	1.50E+02	Not Analyzed	Not Analyzed	2.70E+01
Technesium-99	pCi/L	Not Detected	Not Analyzed	Not Analyzed	2.70E+01
Total Alpha	pCi/L	Not Detected	3.57E+00	3.00E+00	5.60E+00

LERF Basin Leachate

STREAM	Units	Basin 42 Leachate 10/2000	Basin 42 Leachate 9/1998	Basin 43 Leachate 9/1998	Basin 44 Leachate 10/2000
Gross Beta	pCi/L	2.30E+02	1.80E+01	6.60E+01	4.40E+01

ATTACHMENT 3

LETTER REPORT OF LERF DOUBLE-LINER PERFORMANCE

DON'T SAY IT — *Write It!*

DATE: November 18, 1998

TO: Regulation File 2004

FROM: Mark W. Bowman

S6-72

cc: D.L. Flyckt S6-71
T.M. Galioto S6-72
M.D. Guthrie S6-72
L.L. Lin S6-72

Telephone: 373-9379

SUBJECT: LERF BASIN LEACHATE RATES FOR 1997 AND 1998

This DSI addresses concerns of increased LERF leachate rates in 1998. In particular, the leachate rates from LERF Basins 42 and 43 increased in July and August, but decreased to previous levels in September.

CONCLUSIONS

There is no indication the leachate is the result of waste leaking through holes or tears in the polyethylene primary liner between the waste and the leachate sump.

The source of the leachate has not been determined. Based on data from 1997 and 1998, it appears the leachate rate is seasonal, increasing in late spring and decreasing in late summer. This may be caused by a temperature-dependant phenomena such as expansion, diffusion, condensation, or in-leakage. But none of these can adequately explain the leachate rate of 21 gallons per day from Basin 43, while only 1 gallon per day from Basin 44.

The leachate rate is still low. The maximum leachate rate per area was about 26 gallons/acre-day. This is much less than 2100 gallons/acre-day, the "action leak rate" in the RCRA Permit. Since the leachate rate is still low, troubleshooting is not indicated at this time.

DISCUSSION

Figure 1 shows the average leachate rate from each basin in the first 9 months of 1998. The leachate rate in all three basins increased slightly in May then returned to previous levels in early June. In July, the leachate rates for Basins 42 and 43 increased markedly, peaking at 13 gal/day and 21 gal/day, respectively. The values then decreased to previous levels in early September. The leachate rate in Basin 44 did not change during this period. The 1997 data, given in Figure 2, showed similar trends.

In an attempt to determine the source of the leachate, samples of Basin 42 and 43 leachate were taken on September 16. The results are given in Table 1. All gamma-energy analysis results were less than detectable. The Uranium ICP analysis was 4.6 ug/L in the leachate from Basin 43, compared an average value of 270 ug/L for the groundwater in the basin. This indicates the leachate solution is not waste from the basins leaking through the primary liner.

Figures 3 – 5 show the leachate rate versus level for each of the three basins. The leachate rate from Basin 42 increased in the summer while the level in Basin 42 was unchanged. The leachate rate from Basin 43 was increasing during a period when the level in Basin 43 was decreasing. The level in Basin 44 increased slightly during the summer, but the leachate rate was unchanged. There is no correlation between basin level and leachate rate; a further indication that the leachate is not the results of a leak in the primary liner. A leak would be indicated if there was an increase in leachate rate with increasing basin level.

If the leachate is not the result of a leak in the primary liner, what is the source of the water? Several ideas have been proposed, but none can be determined without additional data. There are no raw or sanitary water lines to LERF, so the cause cannot be in-leakage from a man-made source.

The increase in the summer suggests the cause could be condensation of atmospheric moisture or diffusion through a thinner liner caused by expansion from thermal heating. Figures 6 and 7 compare the Basin 43 leachate rate to the ambient temperature and humidity. There appears to be some correlation between temperature, humidity and leachate rate. Moisture in the air may be condensing in the leachate sump as a result of contact with the primary liner or the ground beneath the basins, both of which are below ambient temperature. This implies there is a mechanism for fresh, moist air to enter the sump air space. But the leak rate of 21 gal/day appears to be too great to be from atmospheric condensation alone and could be due to selective diffusion. Assuming a humidity of $8.0\text{E-}3$ lbs H_2O /lbs dry air (a high value in midsummer) and all the moisture in the air condensed, a leachate rate of 21 gallons per day would require a flow-rate of 200 ft^3/min !

Another possibility is water is leaking into the sump from the surrounding soil. This would require penetration of two layers: a 36-inch layer of soil-bentonite, a claylike material with some absorbent qualities, and a polyethylene secondary liner. This would also require free liquid in the surrounding soil. This is very unlikely, particularly in the summer months when there is little precipitation.

There are other theories, but none seem to fully explain the situation. It is recommended that monitoring of leachate trends continue until an exact cause can be determined.

Mark Bowman

Figure 2

1997 LERF Leachate Rate

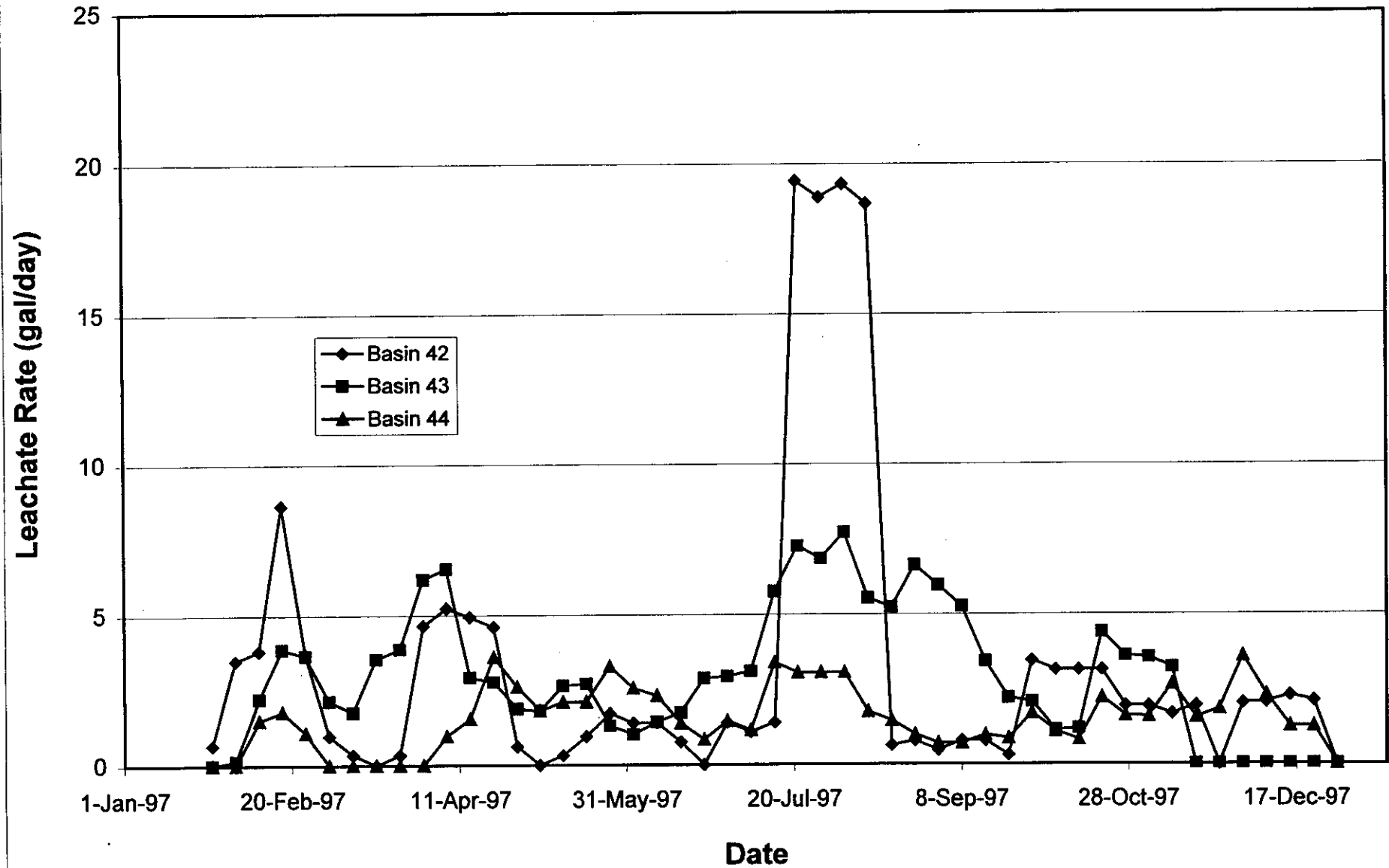


Figure 3

Level versus Leachate Rate - Basin 42

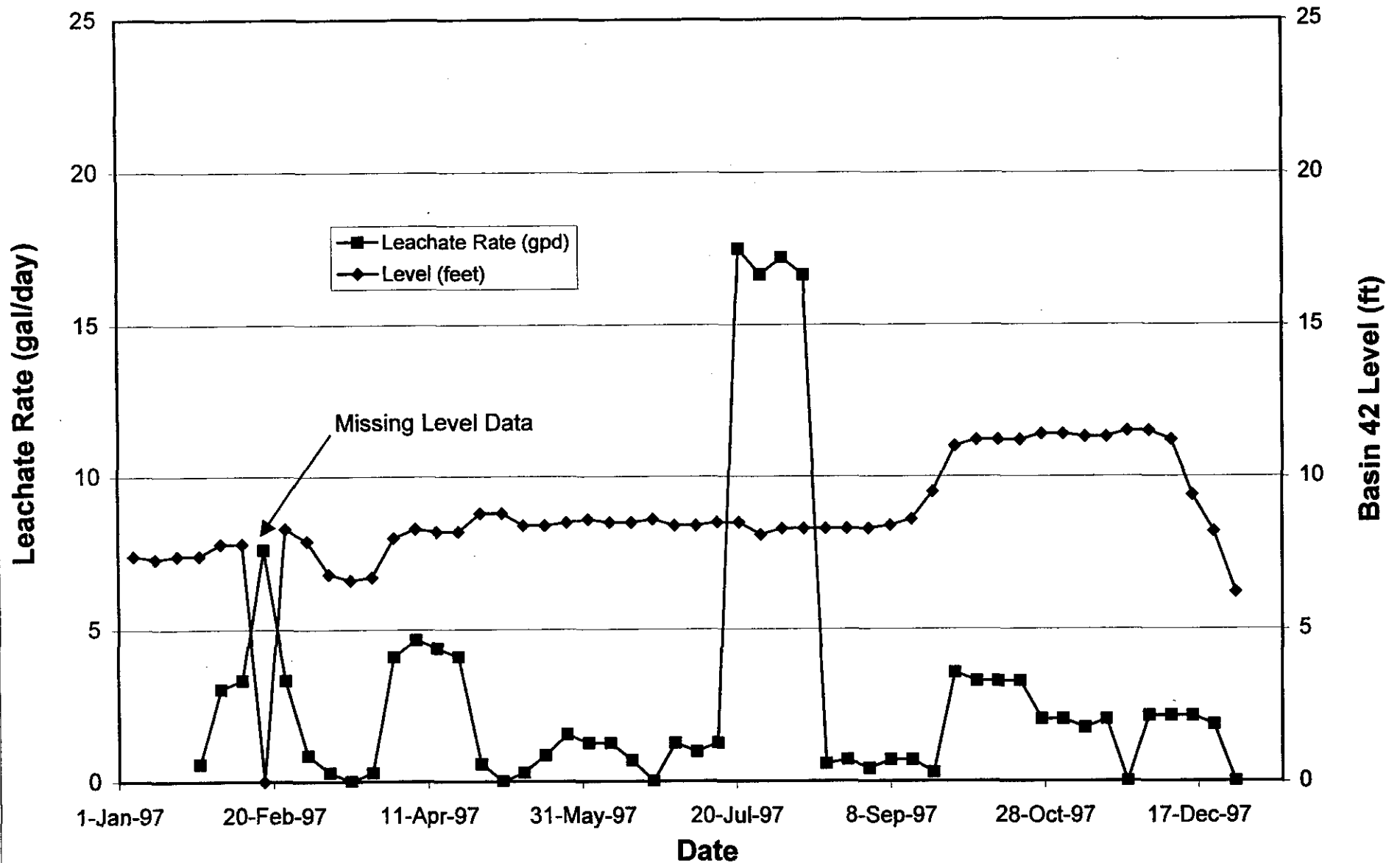


Figure 3

Level versus Leachate Rate - Basin 43

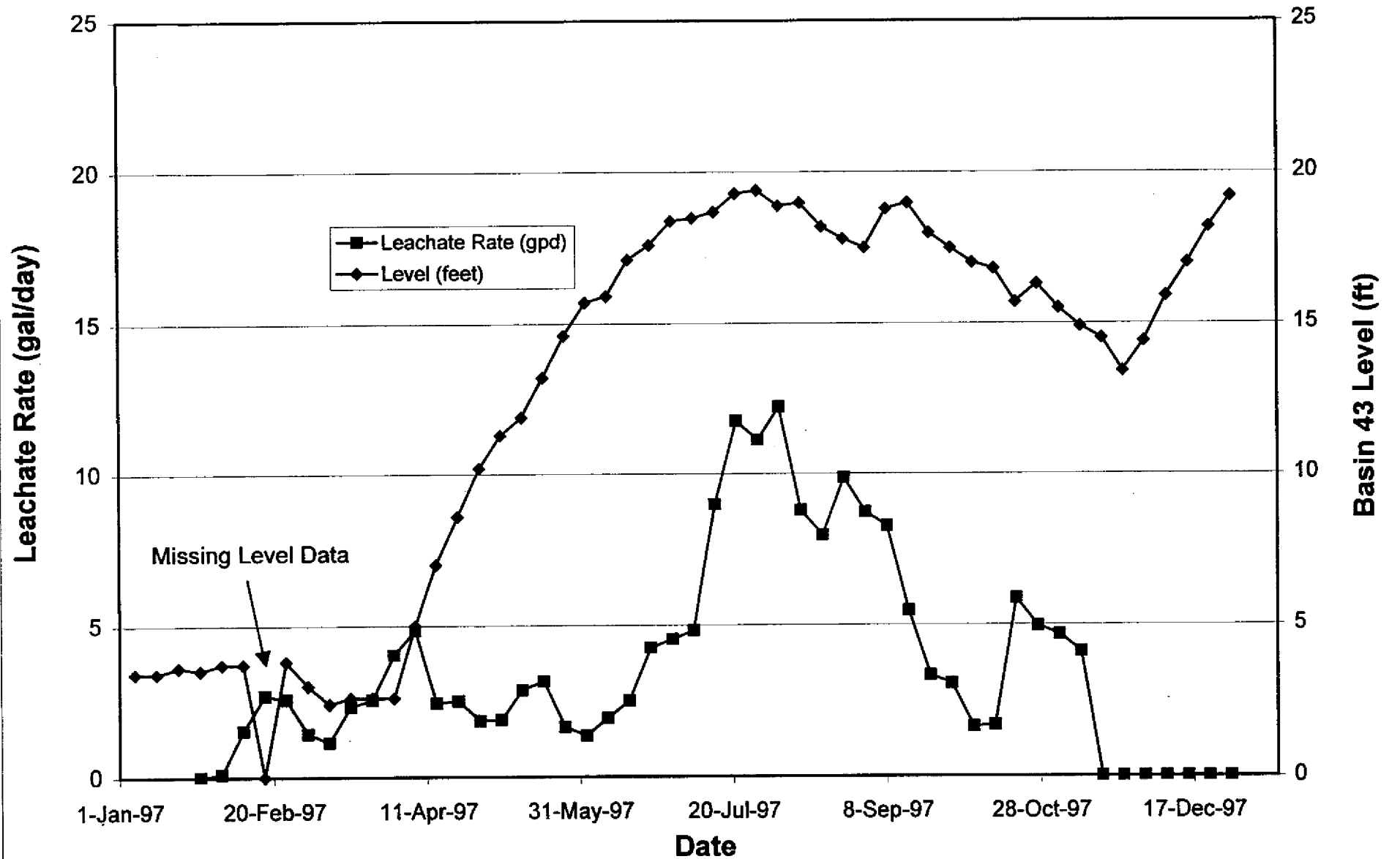


Figure 3

Level versus Leachate Rate - Basin 44

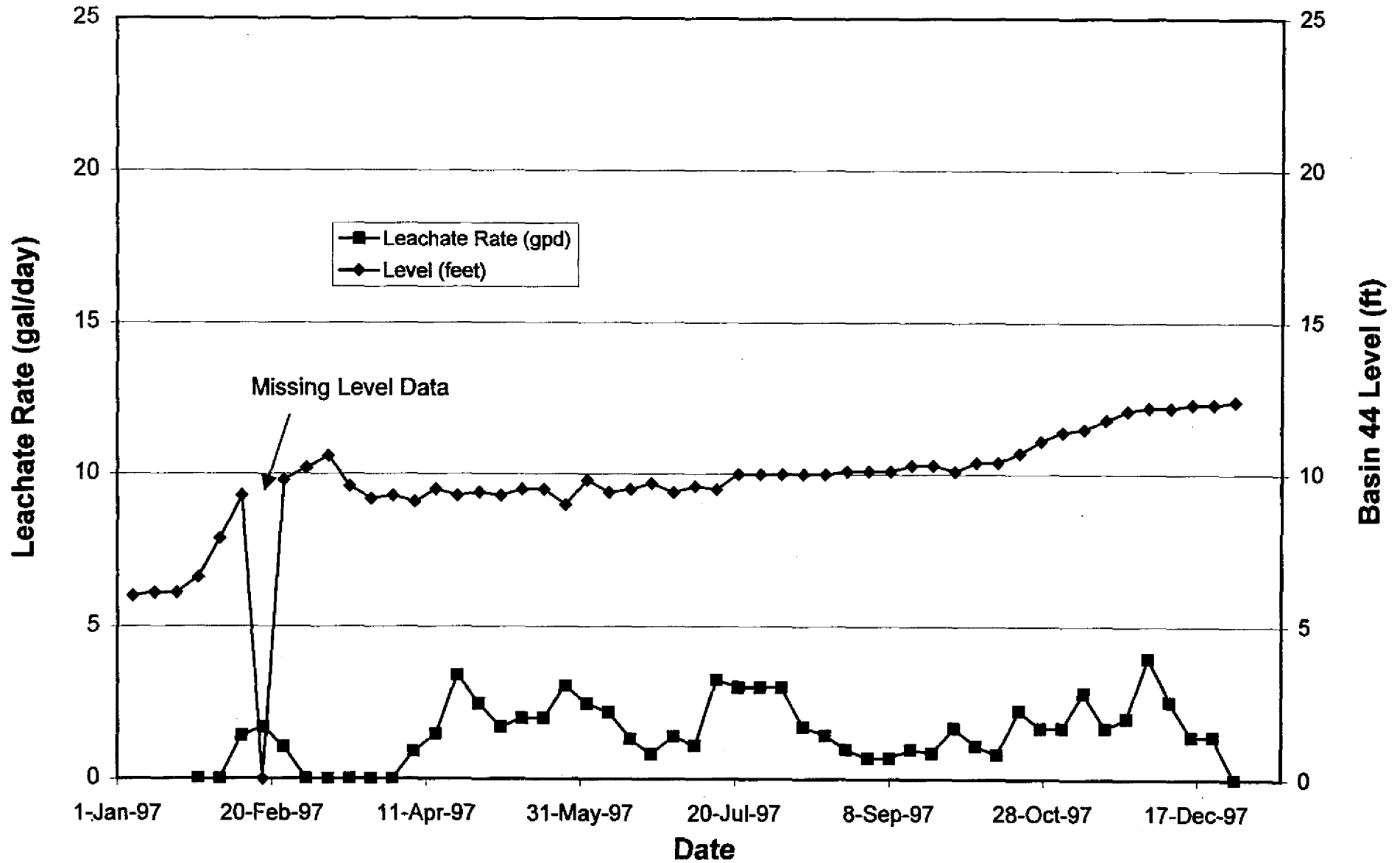
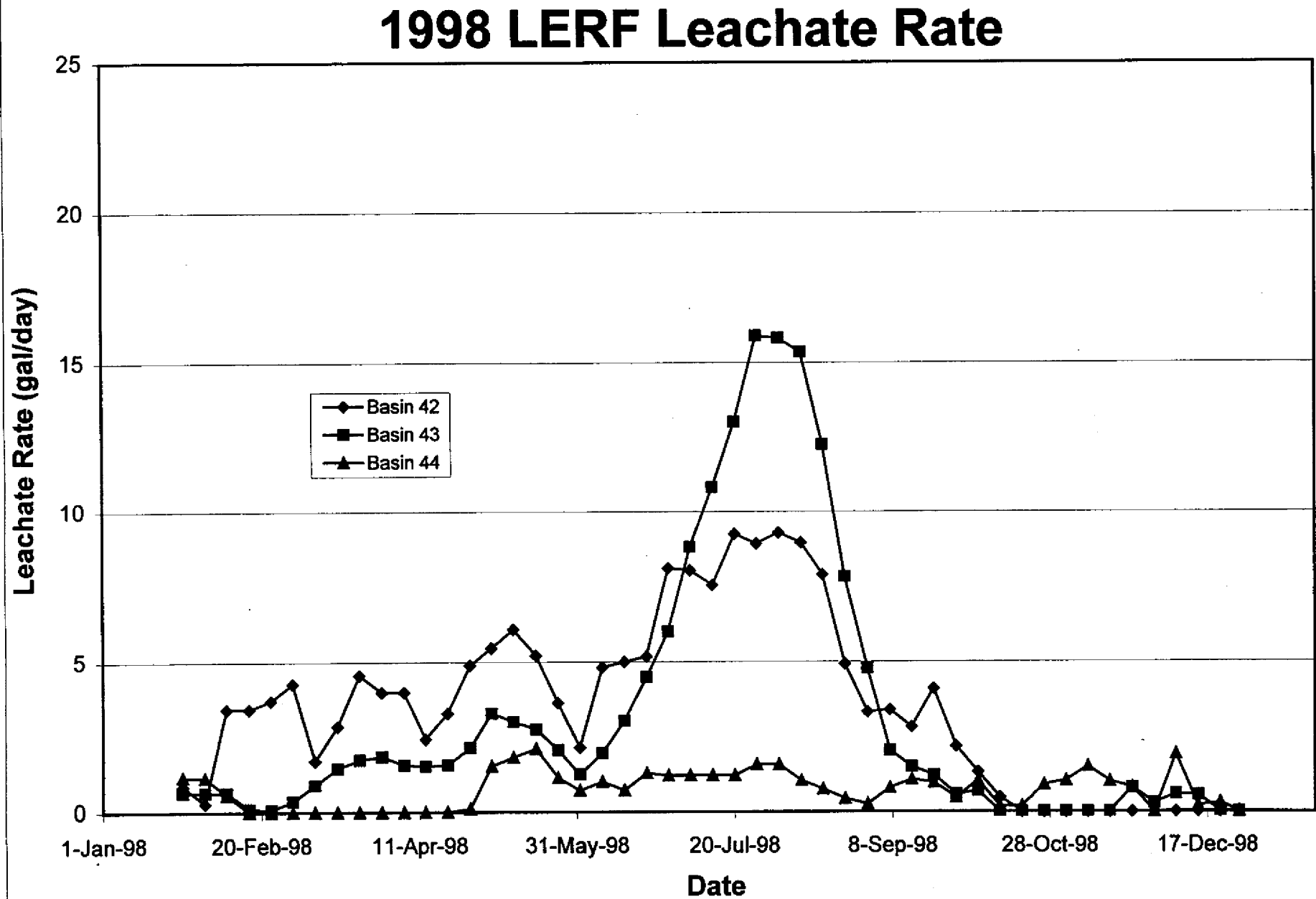
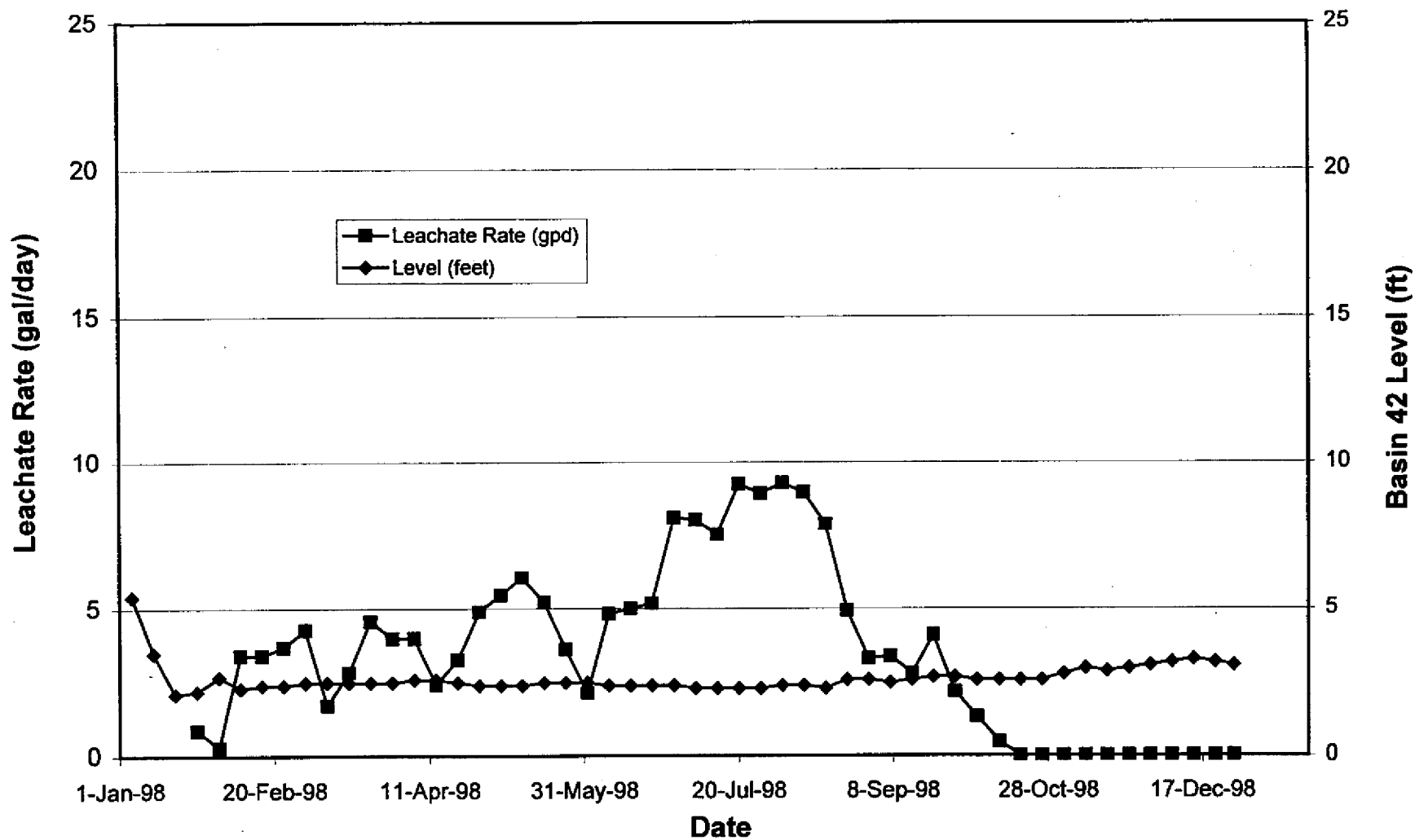


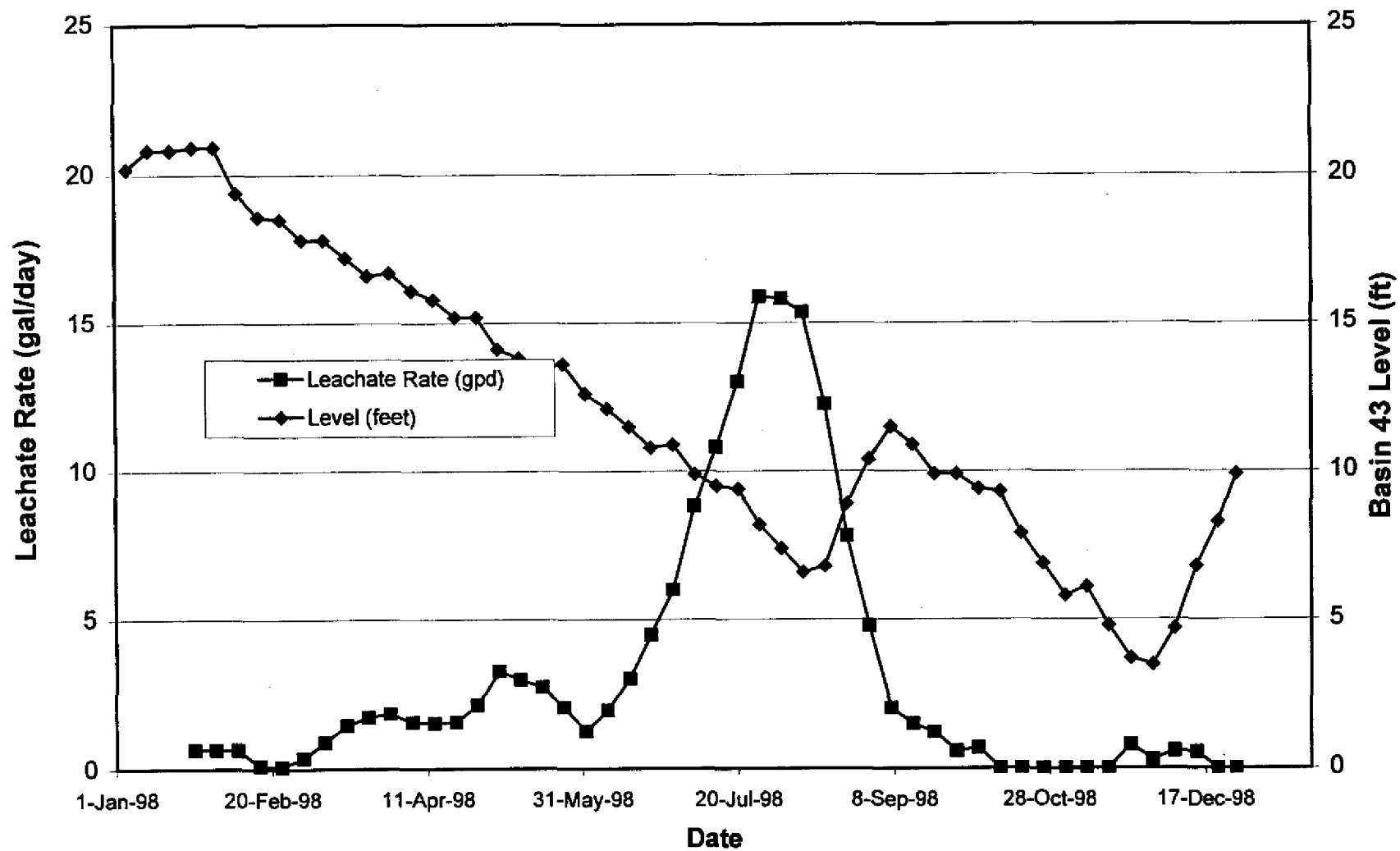
Figure 1



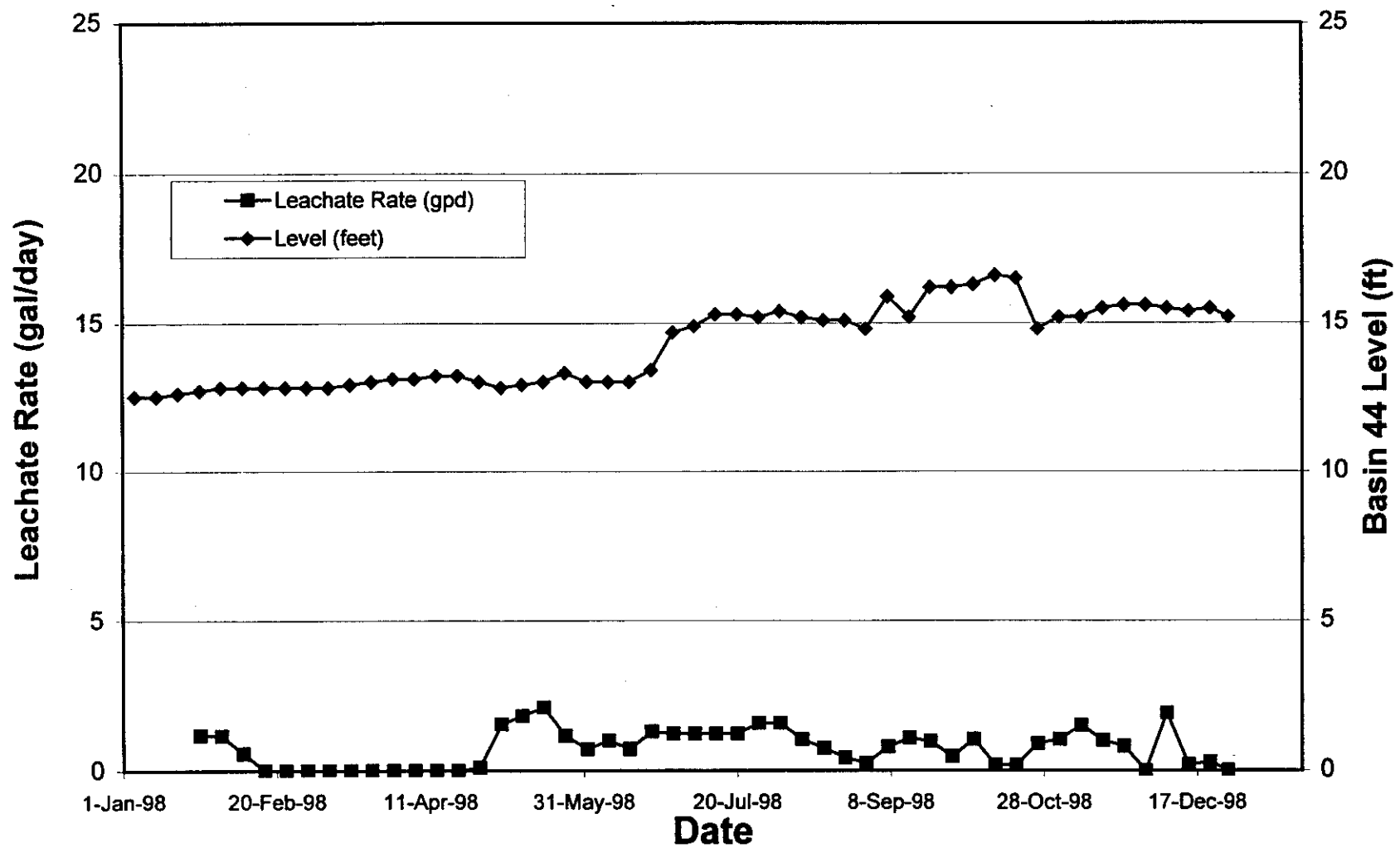
Level versus Leachate Rate - Basin 42



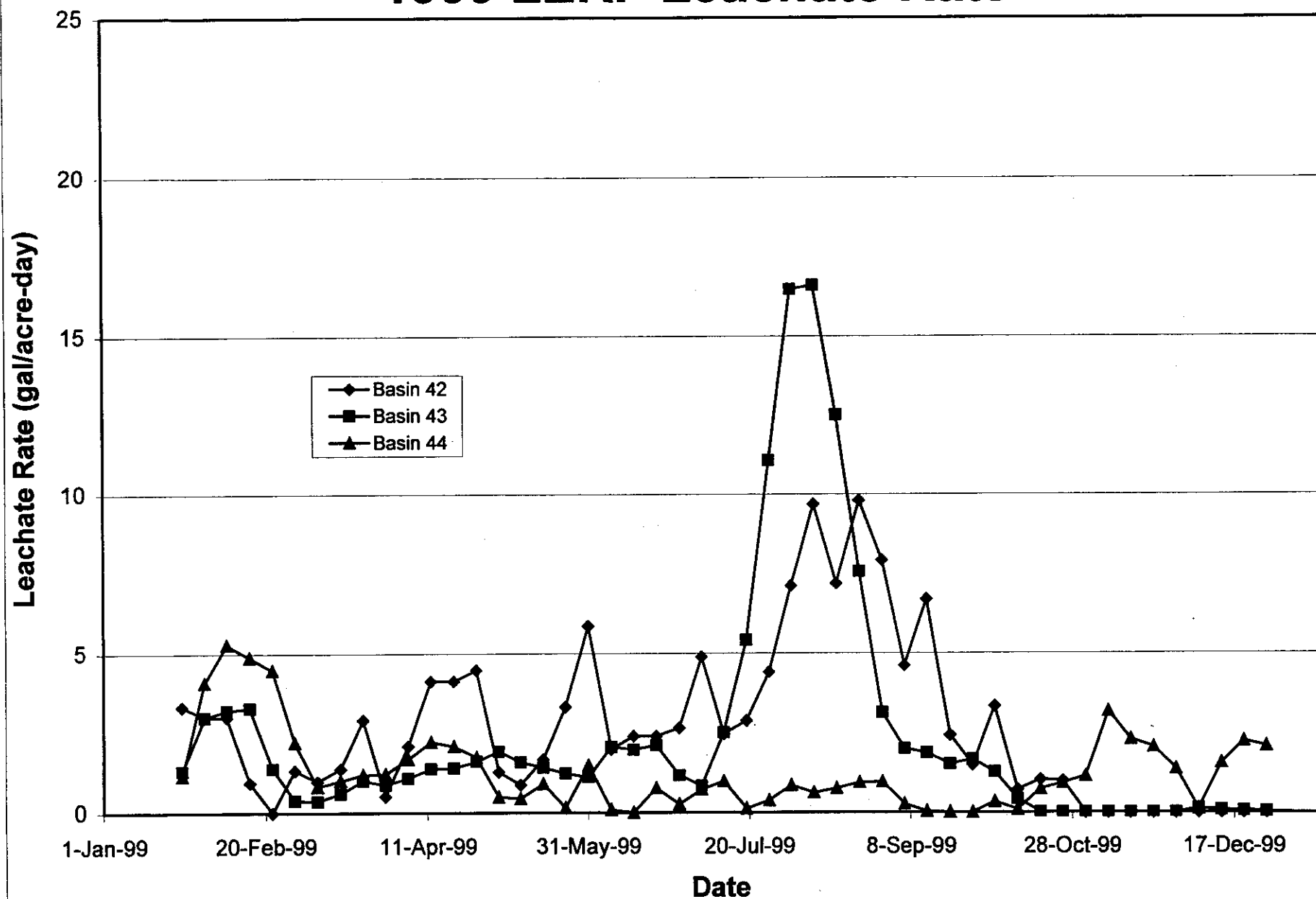
Level versus Leachate Rate - Basin 43



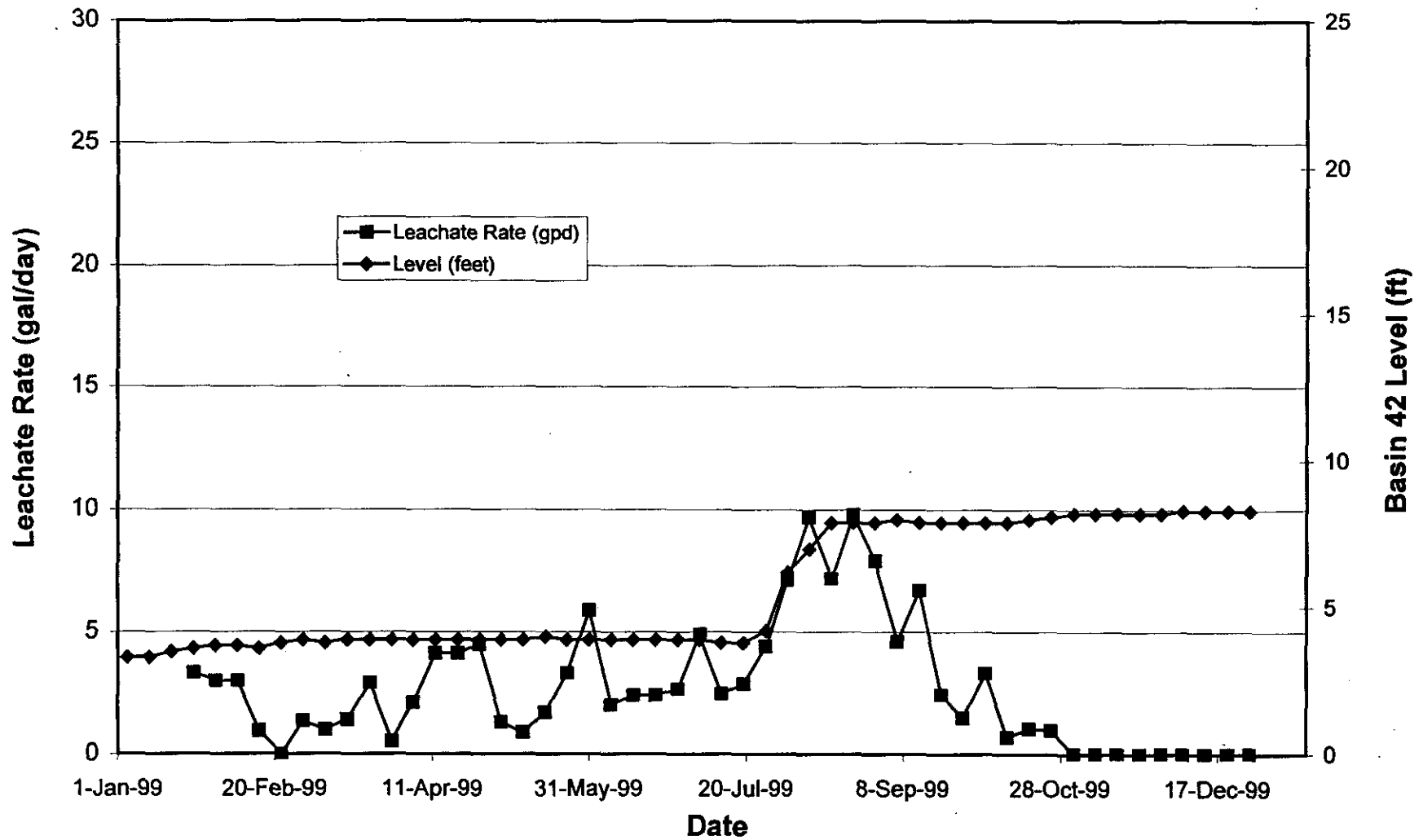
Level versus Leachate Rate - Basin 44



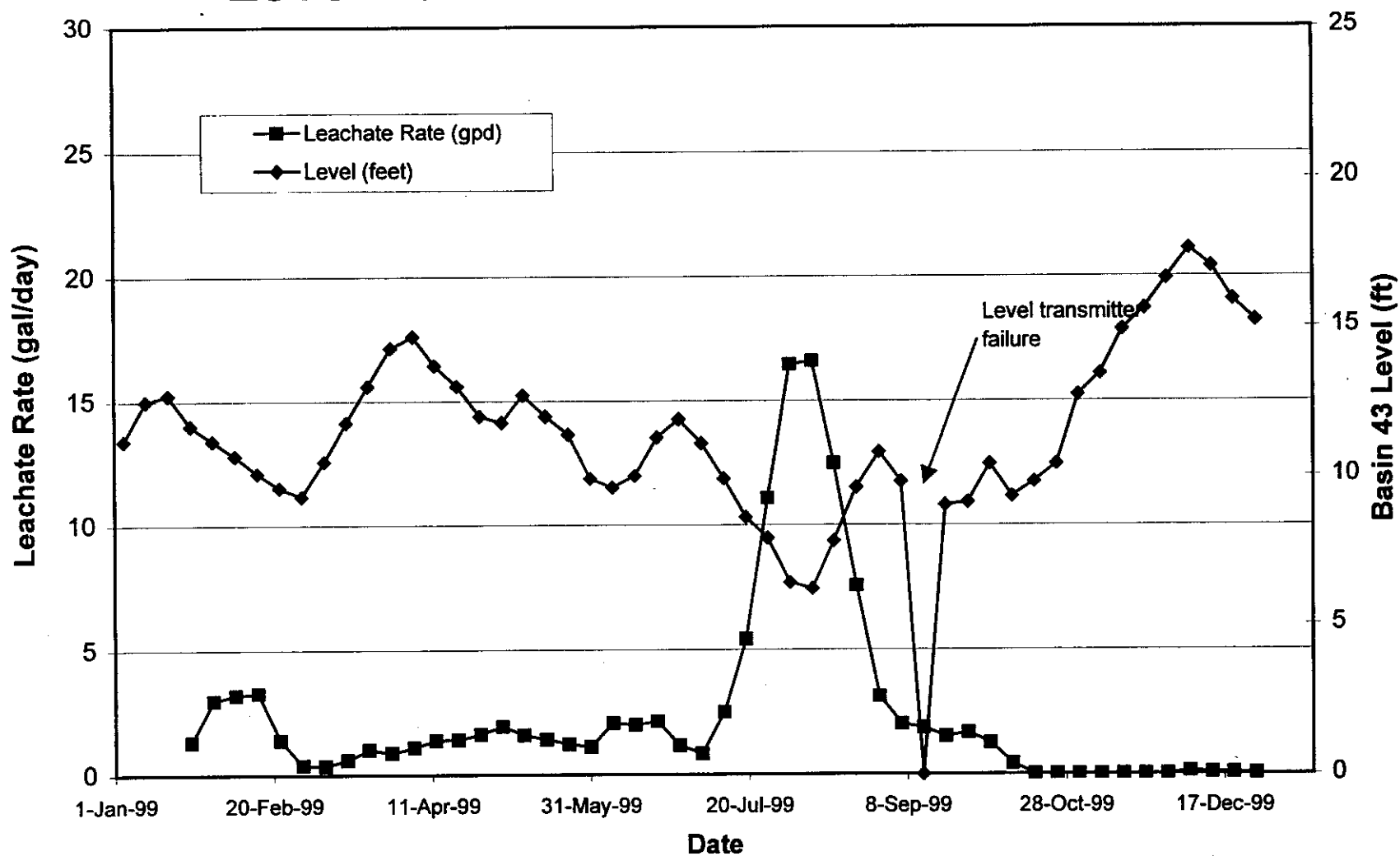
1999 LERF Leachate Rate



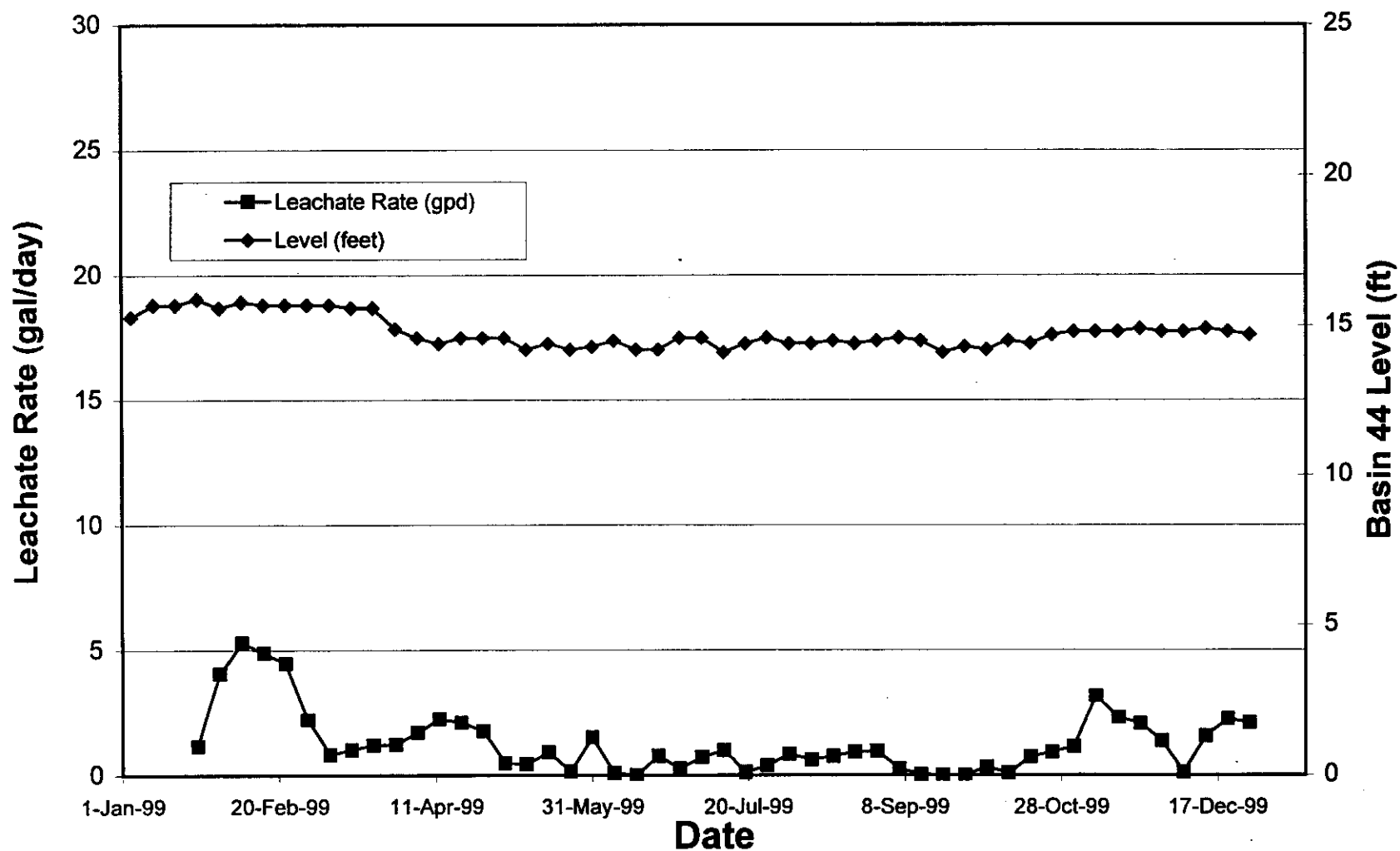
Level versus Leachate Rate - Basin 42



Level versus Leachate Rate - Basin 43



Level versus Leachate Rate - Basin 44



2000 LERF Leachate Rate

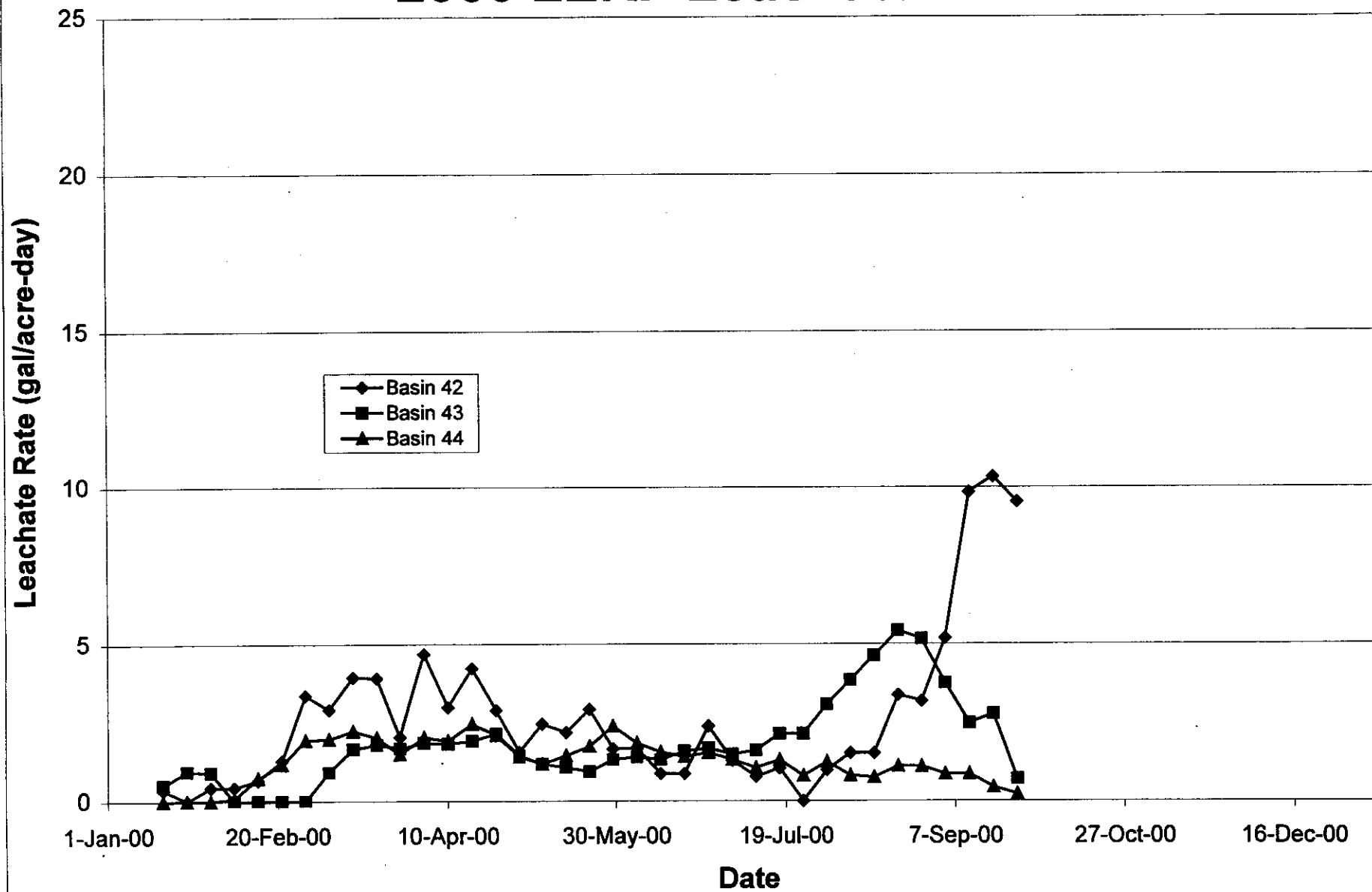
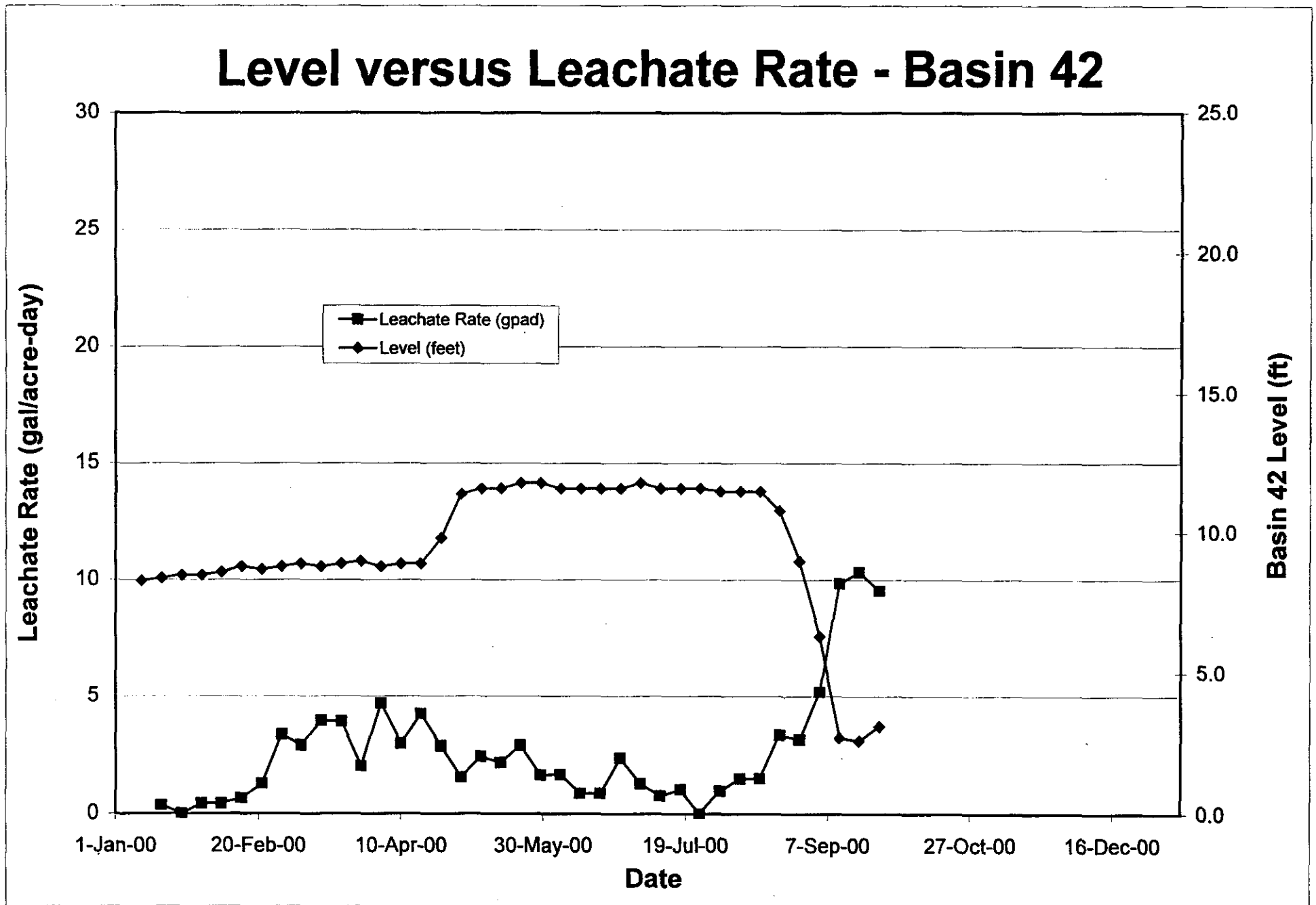
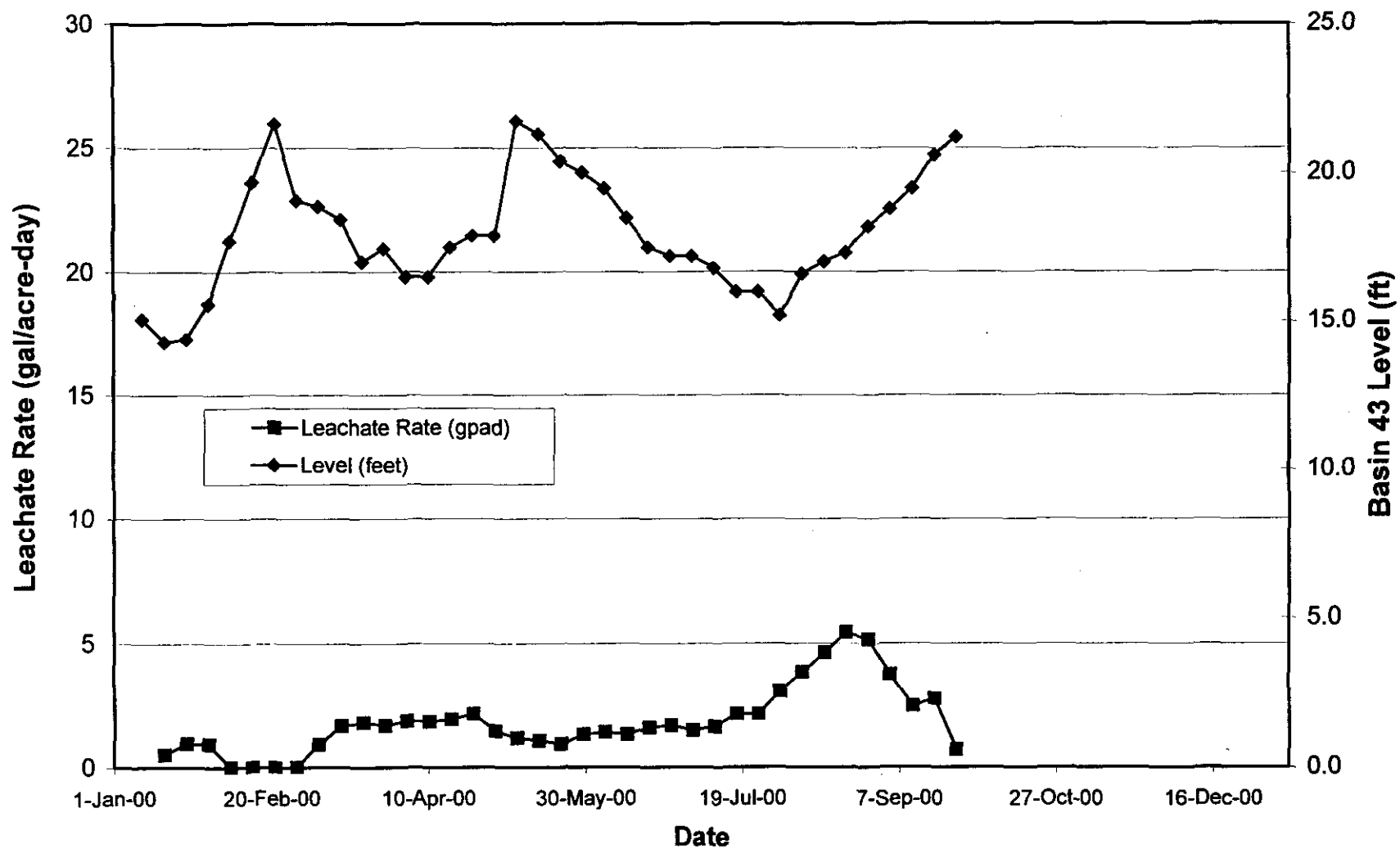


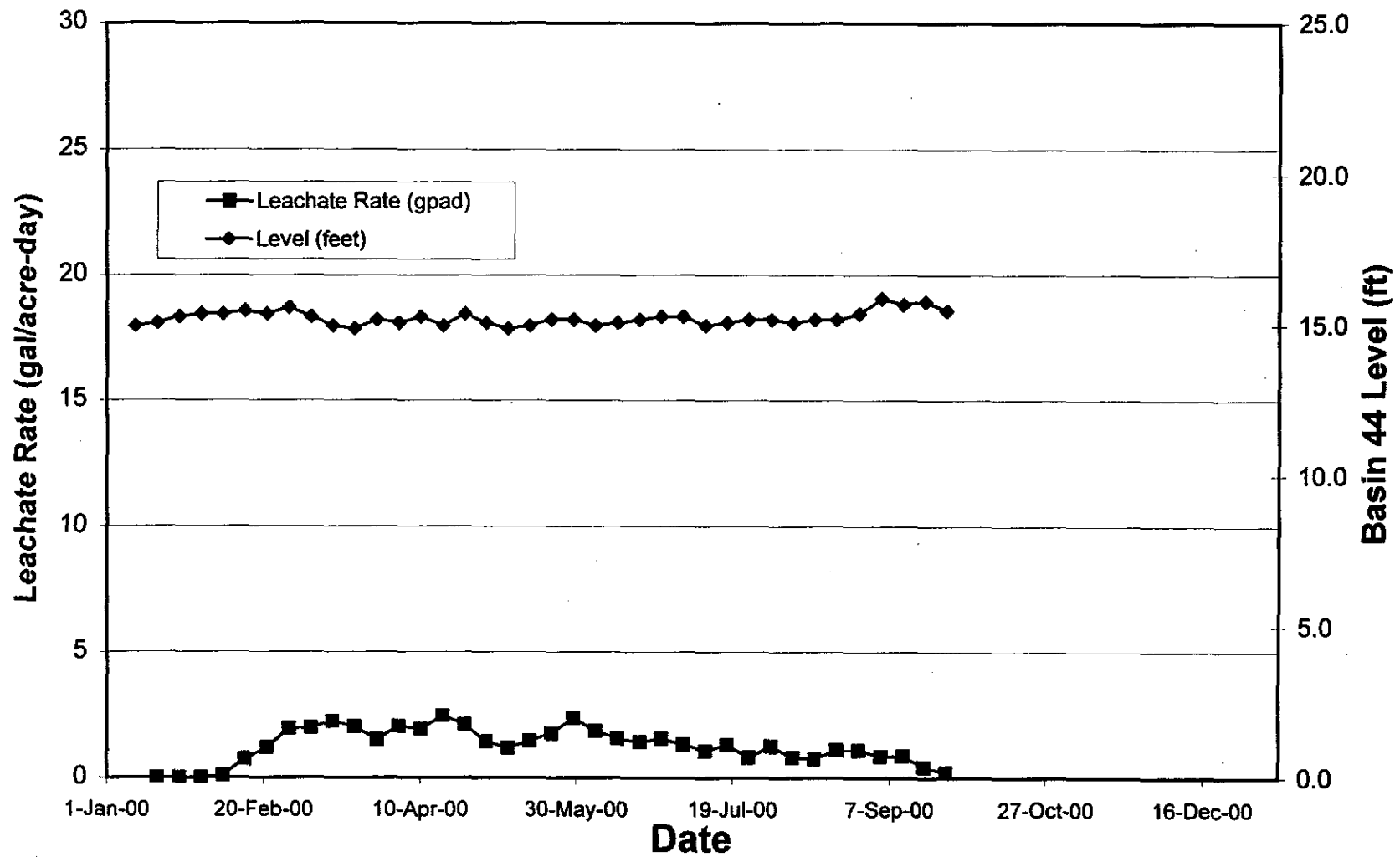
Figure 3



Level versus Leachate Rate - Basin 43



Level versus Leachate Rate - Basin 44



ATTACHMENT 4

LERF LINER SCHEMATICS

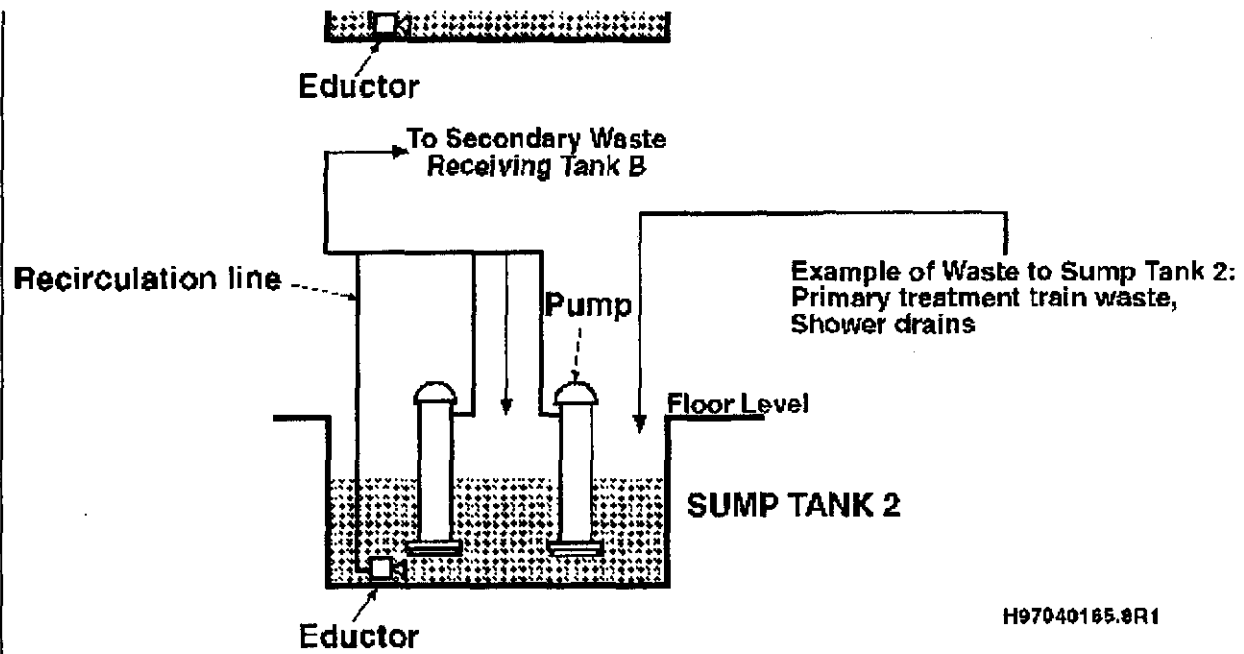
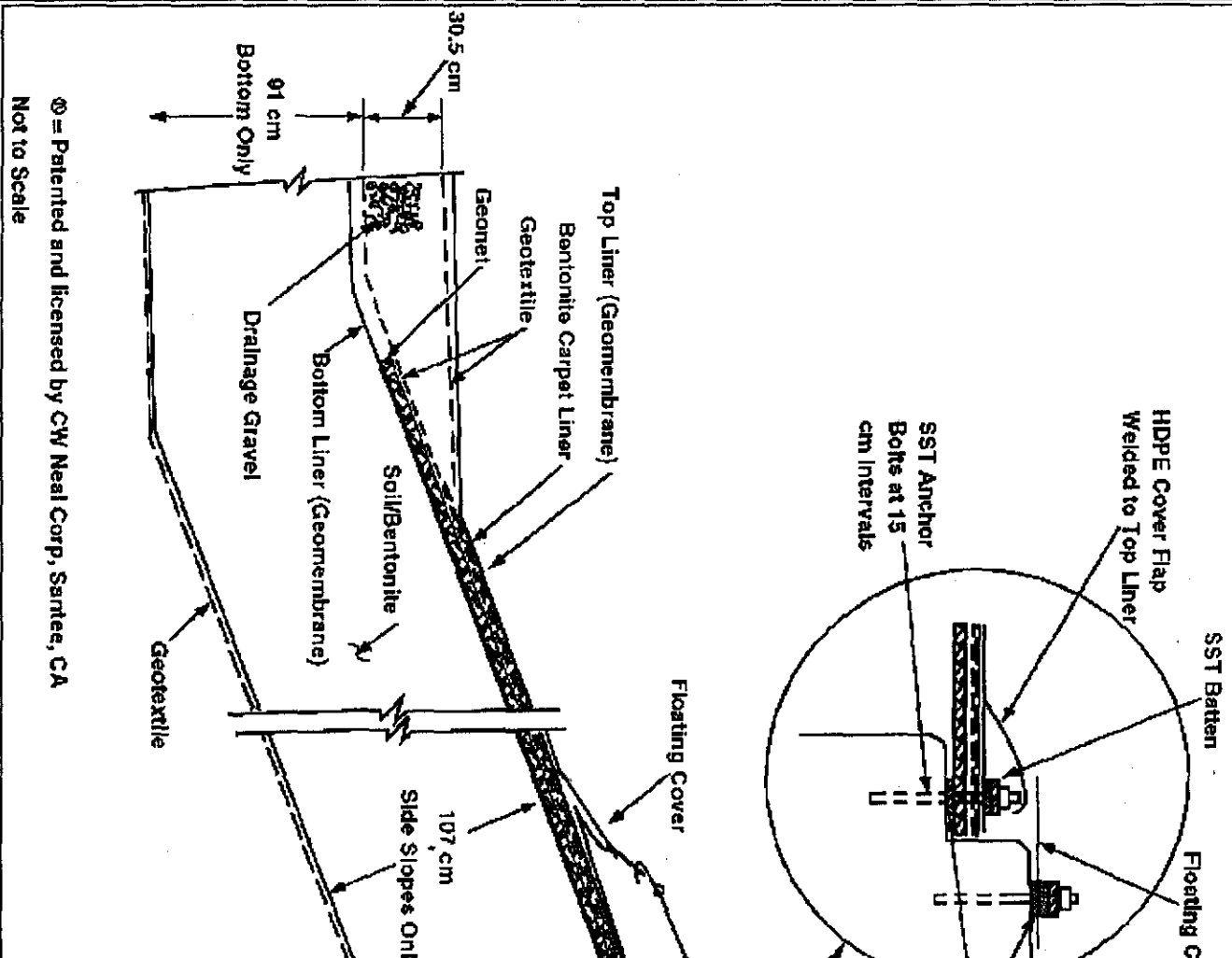


Figure 4-15. Effluent Treatment Facility Sump Tanks.



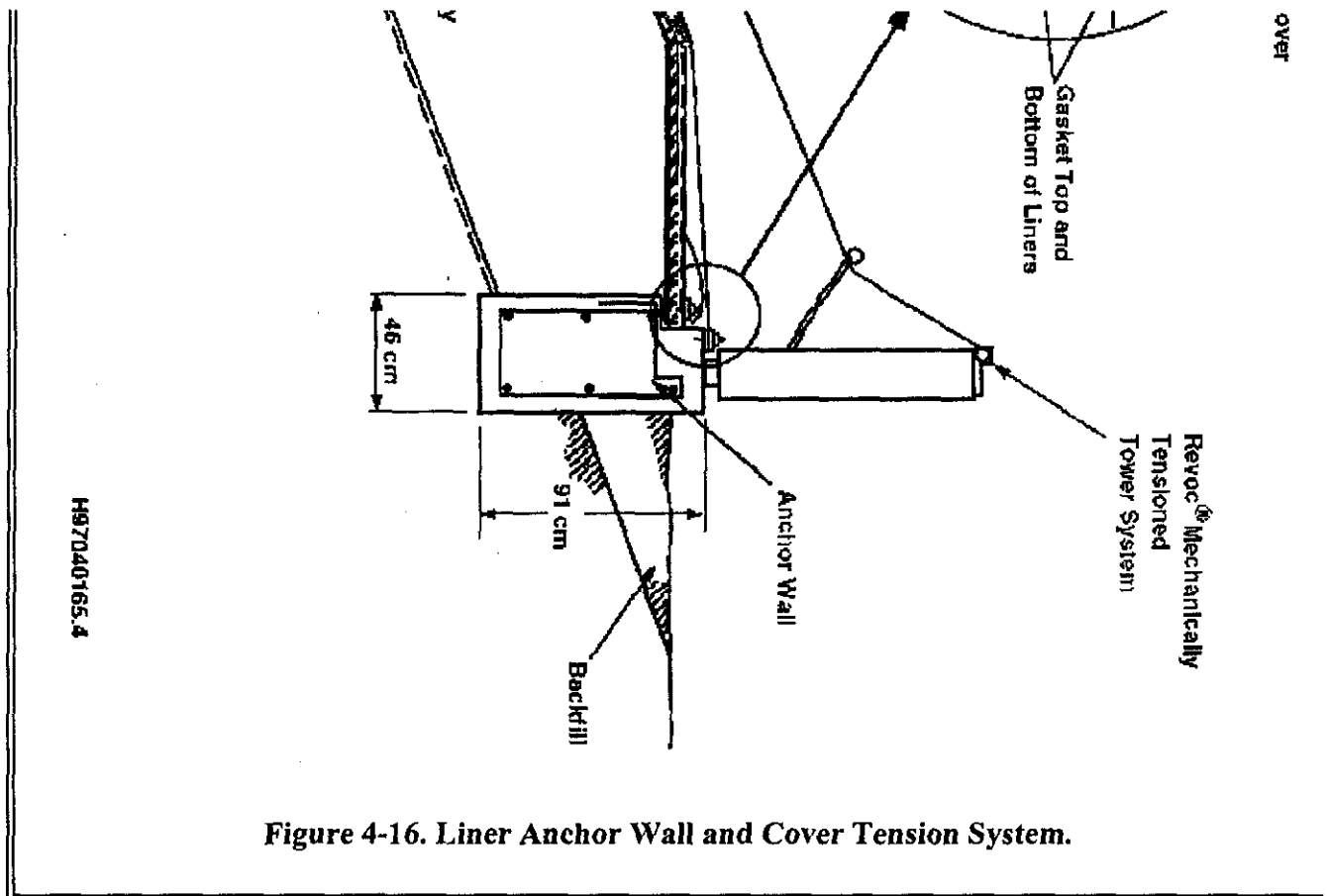


Figure 4-16. Liner Anchor Wall and Cover Tension System.

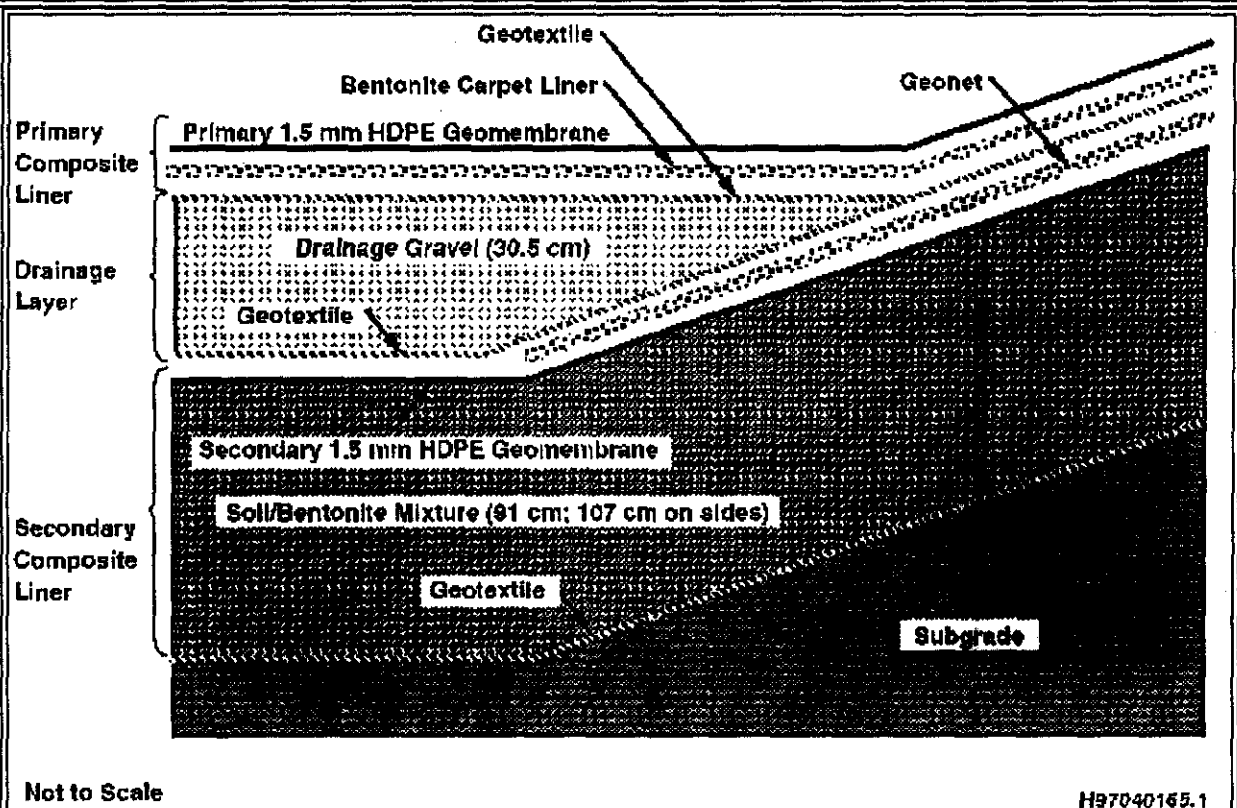
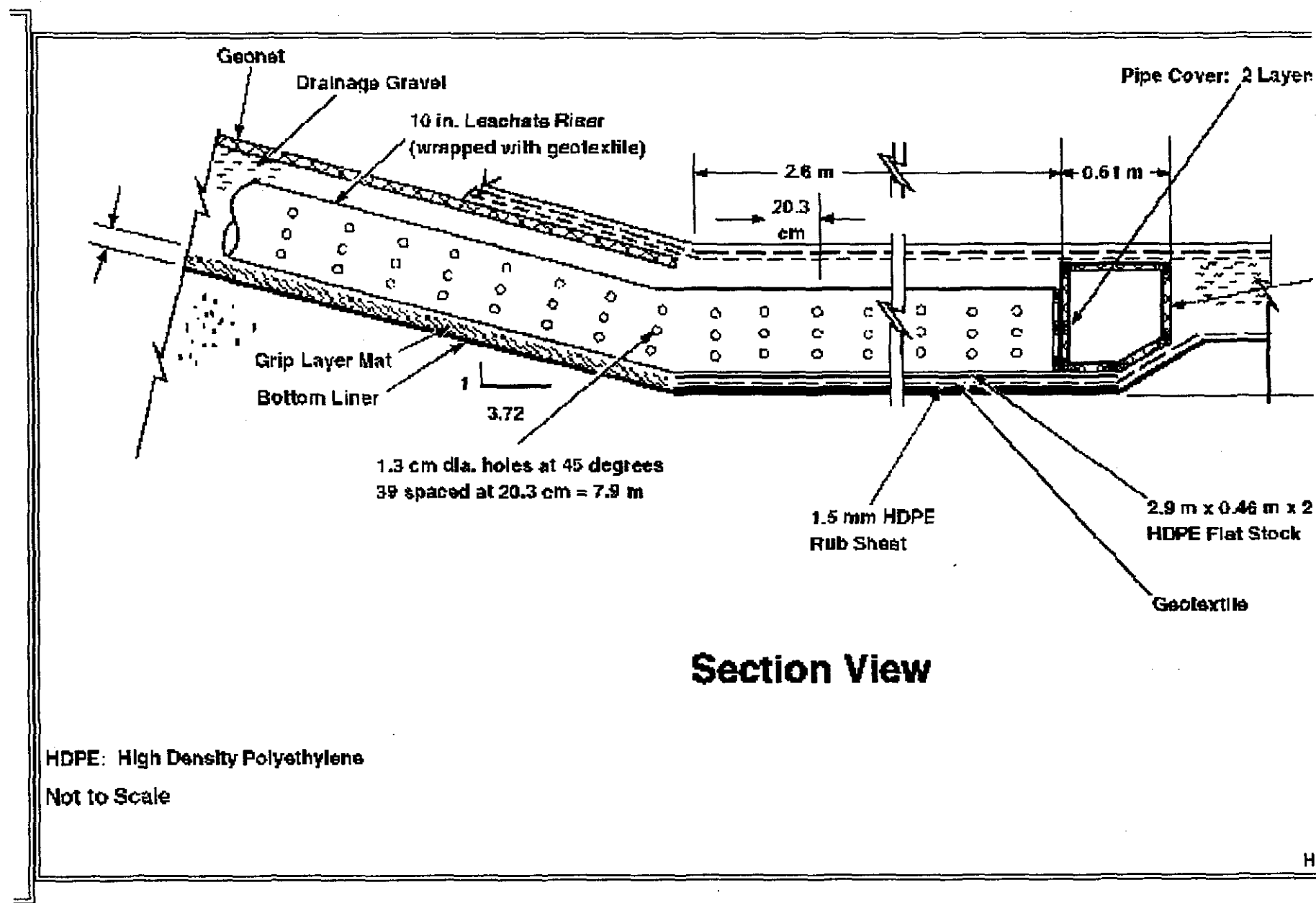
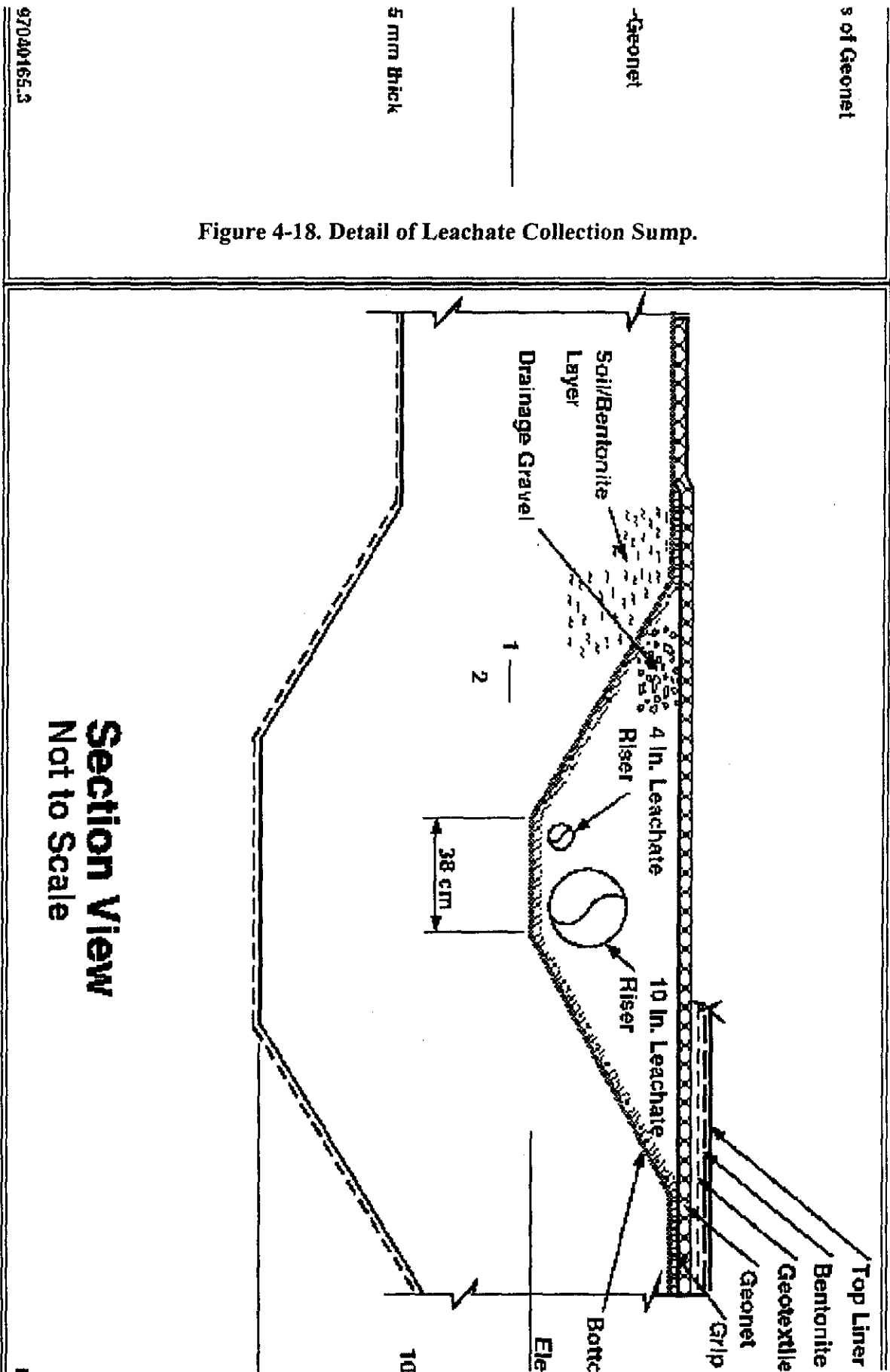


Figure 4-17. Liner System Schematic.






ATTACHMENT 5

***GSE HYPERFLEX* HDPE LINER MANUFACTURER SPECIFICATIONS**

GSE US OPERATIONS		Employment Corporate Home Industry Links Search Contact Us					
PRODUCTS	INSTALLATION SERVICES	FABRICATION	QA/QC	APPLICATIONS	DEALER LOCATIONS	LOCATIONS	DROP-IN SPECIFICATIONS



PRODUCTS

- ▶ DATA SHEET (ENGLISH - PDF) (SPANISH - PDF)
- ▶ PRODUCT QA/QC
- ▶ BIBLIOGRAPHY
- ▶ FAQ
- ▶ E-MAIL FOR MATERIAL

GSE HyperFrictionFlex

CLICK TO GO

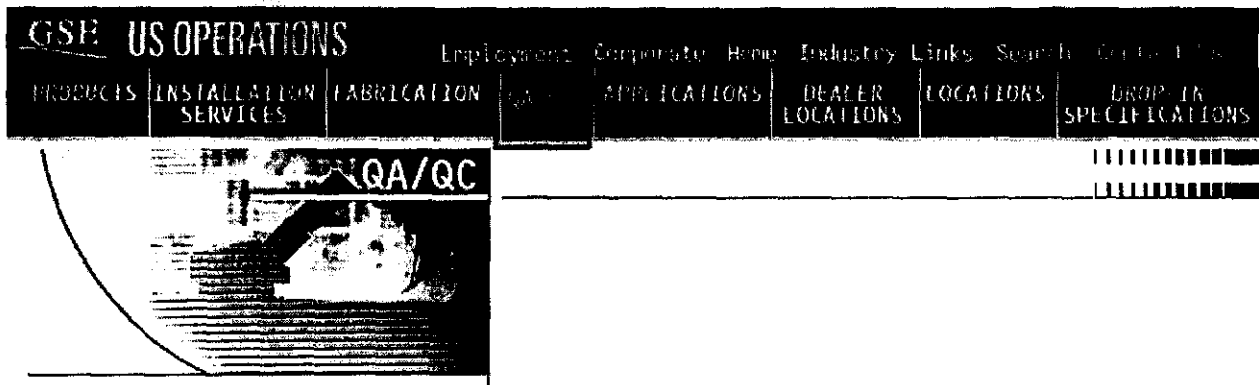
GSE HyperFlex

GSE HyperFlex is a premium grade high density polyethylene (HDPE) geomembrane liner, produced from specially formulated polyethylene resins. This resin and sheet product is specifically designed for geomembrane applications. HyperFlex has a proven history of success with thousands of successful installations covering the most demanding geomembrane applications. GSE HyperFlex is commonly used in buried and exposed applications where chemical and leachate containment are absolutely critical and maximum product life is required. GSE HyperFlex is available in roll widths of 24' (7.3 meters).

- Made from resins specifically designed for geomembrane production.
- Outstanding strength and stiffness properties.
- Excellent chemical resistance
- Demonstrated ability to withstand the rigors of direct exposure to the sun and ultraviolet light
- Proven history of success.
- Backed by the GSE commitment to quality.

- HyperFlex Data Sheet (specification values)
- Frequently Asked Questions: GSE HyperFlex
- Bibliography of Related Articles

[Employment](#) | [Corporate](#) | [Home](#) | [Industry Links](#) | [Search](#) | [Contact Us](#) |
[Products](#) | [Installation Services](#) | [Fabrication](#) | [QA/QC](#) | [Applications](#) | [Dealer Locations](#) | [Locations](#) | [Drop-In Specifications](#) |
[Datasheet](#) | [Product QA/QC](#) | [Bibliography](#) | [FAQ](#) | [E-Mail for Material](#)



GSE Lining Technology, Inc.

Version MN 002 R09/30/00

This manual contains proprietary information belonging to GSE Lining Technology, Inc. This information is intended to provide a summary of standard quality procedures practiced by GSE's Manufacturing Quality Assurance Laboratories in Houston, Texas. These procedures apply to standard geomembrane and drainage materials only and do not explicitly address non-conforming materials.

This manual replaces in its entirety and supersedes all earlier versions issued by GSE Lining Technology, Inc. We suggest you maintain contact with your GSE representative to confirm the validity of this version at future dates.

GSE Lining Technology, Inc. reserves the right to change, modify, or discontinue the use of the policies and procedures described herein without notice or prior consent except as contractually obligated otherwise.

TABLE OF CONTENTS

- I. GSE LINING TECHNOLOGY QUALITY MANIFEST
- II. OVERVIEW OF GSE MANUFACTURING QUALITY ASSURANCE
 - A. OBJECTIVE
 - B. SCOPE
- III. MANUFACTURING QUALITY ASSURANCE ORGANIZATION
- IV. STAFF AND SCHEDULING
- V. PRODUCT IDENTIFICATION AND DOCUMENTATION
 - A. ROLL NUMBERING
 - B. APPROVAL PROCEDURE
 - C. NON-CONFORMANCE
 - D. DOCUMENTATION
- VI. RECORDS RETENTION

- A. RAW MATERIALS
- B. GEOMEMBRANE, GEONET AND GEOCOMPOSITE

VII. TESTING CAPABILITIES

- A. ROUTINE TESTING
- B. OTHER TESTING CAPABILITIES

VIII. MATERIAL QUALITY ASSURANCE

- A. RAW MATERIAL
- B. GEOMEMBRANE PRODUCTS

- 1. ON-LINE MANUFACTURING QUALITY ASSURANCE
- 2. SMOOTH GEOMEMBRANE MATERIALS
- 3. COEXTRUDED TEXTURED GEOMEMBRANES
- 4. FRICTIONFLEX (SPRAY-ON) TEXTURED GEOMEMBRANES

C. GEONET PRODUCTS

- 1. SAMPLING
- 2. EVALUATION OF RESULTS
- 3. REPORTING

D. GEOCOMPOSITE PRODUCTS

E. THIRD PARTY CONFORMANCE SAMPLING

Appendix A - Test Frequencies and Minimum Properties for GSE Raw Materials
Appendix B - Test Frequencies and Minimum Properties for GSE Geomembrane Products
Appendix C - Minimum Weld Properties for GSE Geomembrane Products
Appendix D - Minimum Testing Frequencies for Standard GSE Geonet and Geocomposite Products

Next

| Corporate | Home | Industry Links | Search | Contact Us | Employment |
| Products | Installation Services | QA/QC | Applications | Dealer Locations | Locations | Drop-In
Specifications |



INTRODUCTION TO SAMPLE SPECIFICATIONS

GSE is the world leader in providing geosynthetic lining solutions, products and services to satisfy the needs of domestic and international and public and private companies engaged in waste management, wastewater treatment, mining, aquaculture and other industrial activities.

Gundle/SLT Environmental, Inc., the parent company of GSE, is a corporation formed in July 1995 by the merger of Gundle Environmental Systems, Inc. and SLT Environmental, Inc. It is listed on the New York Stock Exchange under the symbol "GSE". The company's headquarters and two separate manufacturing facilities are located in Houston, Texas. GSE's Gundseal GCL clay lining manufacturing plant is located in Spearfish, South Dakota, USA. Other manufacturing facilities are located in Germany, the United Kingdom, Thailand and Egypt.

GSE is the leading worldwide manufacturer, supplier and installer of flexible geomembrane lining systems used to line and cap sanitary and hazardous waste landfills, to contain materials generated in certain mining processes and to contain liquids (potable, sanitary, wastewater and hazardous) and industrial products in ponds, tanks, pits, lagoons, reservoirs and canals.

GSE's lining systems meet the highest design criteria in the industry. The principal component of these lining systems is a geosynthetic membrane ranging from 20 mils to 240 mils (0.5 mm to 6.0 mm) in thickness. More complex liner systems may consist of several membrane liners interlaid with geosynthetic clay liners, geotextiles, reinforcing geogrids and synthetic drainage materials. The flexible geomembrane lining panels are generally welded together at the customer's jobsite using either an extrusion or a fusion (hot wedge) process. The welded seams are tested on site and in GSE's laboratory, on request, as part of its Installation Quality Assurance Program.

SECTION 02621

GEOCOMPOSITE DRAINAGE LAYER

PART 1: GENERAL

1.01 SECTION INCLUDES

- A. Specifications and guidelines for MANUFACTURING and INSTALLING geocomposite.

1.02 REFERENCES

- A. American Society for Testing and Materials (ASTM)
 - 1. D 1505-98 Standard Test Method for Density of Plastics by the Density-Gradient Technique
 - 2. D 1603-94 Standard Test Method for Carbon Black in Olefin Plastics
 - 3. D 1621-94 Standard Test Method for Compressive Properties of Rigid Cellular Plastics
 - 4. D 4218-96 Standard Test Method for the Determination of Carbon Black Content in Polyethylene Compounds by the Muffle-Furnace Technique
 - 5. D 4533-91 (1996) Standard Test Method for Trapezoid Tearing Strength of Geotextiles
 - 6. D 4595-86 (1994) Standard Test Method for Tensile Properties of Geotextiles by the Wide Width Strip Method
 - 7. D 4632-91 (1997) Standard Test Method for Grab Breaking Load and Elongation of Geotextiles
 - 8. D 4716-99 Standard Test Method for Determining the (In-Plane) Flow Rate Per Unit Width and Hydraulic Transmissivity of a Geosynthetic Using a Constant Head
 - 9. D 4751-99 Standard Test Method for Determining Apparent Opening Size of a Geotextile
 - 10. D 4833-88 (1996) Standard Test Method for Index Puncture Resistance of Geotextiles, Geomembranes and Related Products
 - 11. D 5035-95 Standard Test Method for Breaking Force and Elongation of Textile Fabrics (Strip Method)
 - 12. D 5199-99 Standard Test Method for Measuring Nominal Thickness of Geotextiles and Geomembranes
- B. Geosynthetic Research Institute (GRI)
 - 1. GRI GC-7 Determination of Adhesion and Bond Strength of Geocomposites.
- C. Relevant publications from the Environmental Protection Agency (EPA):
 - 1. Daniel, D.E. and R.M. Koerner, (1993), *Technical Guidance Document: Quality Assurance and Quality Control for Waste Containment Facilities*, EPA/600/R-93/182.

1.03 DEFINITIONS

- A. Construction Quality Assurance Consultant (CONSULTANT)- Party, independent from MANUFACTURER and INSTALLER that is responsible for observing and documenting activities related to quality assurance during the lining system construction.
- B. ENGINEER- The individual or firm responsible for the design and preparation of the project's Contract Drawings and Specifications.
- C. Geocomposite Manufacturer (MANUFACTURER)- The party responsible for manufacturing the geocomposite rolls.
- D. Geosynthetic Quality Assurance Laboratory (TESTING LABORATORY)- Party, independent from the MANUFACTURER and INSTALLER, responsible for conducting laboratory tests on samples of geosynthetics obtained at the site or during manufacturing, usually under the direction of the OWNER.
- E. INSTALLER- Party responsible for field handling, transporting, storing and deploying the geocomposite.
- F. Lot- A quantity of resin (usually the capacity of one rail car) used to manufacture polyethylene geocomposite rolls. The finished rolls will be identified by a roll number traceable to the resin lot.

1.04 QUALIFICATIONS

A. MANUFACTURER

- 1. Geocomposite shall be manufactured by the following:
 - a. GSE Lining Technology, Inc.
 - b. approved equal
- 2. MANUFACTURER shall have manufactured a minimum of 10,000,000 square feet of polyethylene geocomposite material during the last year.

B. INSTALLER

- 1. Installation shall be performed by one of the following installation companies (or approved equal):
 - a. GSE Lining Technology, Inc.
 - b. GSE Approved Dealer/ Installer
- 2. INSTALLER shall have installed a minimum of [] square feet of geocomposite in the last [] years.
- 3. INSTALLER shall have worked in a similar capacity on at least [] projects similar in complexity to the project described in the contract documents, and with in at least [] square feet of geonet installation on each project.

4. The Installation Supervisor shall have worked in a similar capacity on projects similar in size and complexity to the project described in the Contract Documents.

1.05 MATERIAL LABELING, DELIVERY, STORAGE AND HANDLING

- A. Labeling- Each roll of geocomposite delivered to the site shall be wrapped and labeled by the MANUFACTURER. The label will identify:
 1. manufacturer's name
 2. product identification
 3. length
 4. width
 5. roll number
- B. Delivery- Rolls of geonet will be prepared to ship by appropriate means to prevent damage to the material and to facilitate off-loading.
- C. Storage- The on-site storage location for the geocomposite, provided by the CONTRACTOR to protect the geonet from abrasions, excessive dirt and moisture shall have the following characteristics:
 1. level (no wooden pallets)
 2. smooth
 3. dry
 4. protected from theft and vandalism
 5. adjacent to the area being lined
- D. Handling
 1. The CONTRACTOR and INSTALLER shall handle all geocomposite in such a manner as to ensure it is not damaged in any way.
 2. The INSTALLER shall take any necessary precautions to prevent damage to underlying layers during placement of the geocomposite.

1.06 WARRANTY

- A. Material shall be warranted, on a pro-rata basis against defects for a period of 1-year from the date of the geocomposite installation.
- B. Installation shall be warranted against defects in workmanship for a period of 1-year from the date of geocomposite completion.

PART 2: PRODUCTS

2.01 GEOCOMPOSITE PROPERTIES

- A. A geocomposite shall be manufactured by extruding (two crossing strands to form a bi-planer drainage net structure) (three sets of strands to form a Tri-Planer drainage net structure consisting of a thick vertical rib with diagonally placed top and bottom ribs) with a non-woven geotextile bonded to one or both sides.

- B. The geocomposite specified shall have properties that meet or exceed the values listed in Tables 02621-1 and 02621-2 (bi-planer) or 02621-3 (tri-planer) and 02621-4.

Table 02621-1

Standard Property Drainage Sheet GSE FabriCap (Bi-Planer)			
Tested Property	Test Method	MINIMUM AVERAGE VALUES^(e)	
		6 oz/yd²	8 oz/yd²
Transmissivity ^(a) , m ² /sec	ASTM D4716-99	1.0X10 ⁻⁴	9.0X10 ⁻⁵
Ply Adhesion, lb/in (N/mm)	GRI GC-7	See footnote (b)	See footnote (b)
Roll Width, ft (m)		14 (4.3)	14 (4.3)
Roll Length ^(d) , ft (m)		225 (68.6)	200 (60.9)
Net Component Only^(c)			
Transmissivity ^(a) , m ² /sec	ASTM D4716-99	1X10 ⁻³	1X10 ⁻³
Thickness, mil (mm)	ASTM D 5199	200 (5.0)	200 (5.0)
Density, g/cm ³	ASTM D 1505	0.94	0.94
Tensile Strength (MD), lb/in (N/mm)	ASTM D 5035	32 (5.6)	32 (5.6)
Carbon Black Content, %	ASTM D 1603	2.0	2.0
Geotextile Component Only^(c,d)			
Thickness, mil (mm)	ASTM D 5199	70 (1.7)	90 (2.2)
Grab Tensile, lb (N)	ASTM D 4632	150 (667)	205 (911)
Puncture Strength, lb (N)	ASTM D 4833	85 (378)	110 (485)
AOS, US Sieve (mm)	ASTM D 4751	70 (0.212)	80 (0.180)
Flow Rate, gpm/ft ² (lpm/m ²)	ASTM D 4491	110 (4480)	110 (4480)
UV Resistance, % retained	ASTM D 4355 (after 500 hours)	70	70

(a) Gradient of 1.0, normal load of 4,000 psf, water at 70° between stainless steel plates.

(b) Greater than the friction angle of the textile to soil.

(c) Component properties prior to lamination.

(d) Other geotextiles are available and may be provided as agreed upon by GSE. All geotextile property values are as reported by the geotextile supplier.

(e) These are typical values and are based on the cumulative results of specimens tested and as determined by GSE Quality Assurance practices.

Table 02621-2

Project Number:

02621-5

9/29/00

Standard Property Drainage Sheet GSE FabriNet (Bi-Planer)				
Tested Property	Test Method	MINIMUM AVERAGE VALUES ^(e)		
		6 oz/yd ²	8 oz/yd ²	10 oz/yd ²
Transmissivity ^(a) , m ² /sec	ASTM D4716-99	6.0X10 ⁻⁵	4.0X10 ⁻⁵	3.0X10 ⁻⁵
Ply Adhesion, lb/in (N/mm)	GRI GC-7	See footnote (b)	See footnote (b)	See footnote (b)
Roll Width, ft (m)		14 (4.3)	14 (4.3)	14 (4.3)
Roll Length ^(d) , ft (m)		225 (68.6)	200 (60.9)	190 (58.0)
Net Component Only ^(c)				
Transmissivity ^(a) , m ² /sec	ASTM D4716-99	1X10 ⁻³	1X10 ⁻³	1X10 ⁻³
Thickness, mil (mm)	ASTM D 5199	200 (5.0)	200 (5.0)	200 (5.0)
Density, g/cm ³	ASTM D 1505	0.94	0.94	0.94
Tensile Strength (MD), lb/in (N/mm)	ASTM D 5035	45 (7.9)	45 (7.9)	45 (7.9)
Carbon Black Content, %	ASTM D 1603	2.0	2.0	2.0
Geotextile Component Only ^(c,d)				
Thickness, mil (mm)	ASTM D 5199	80 (2.0)	90 (2.2)	105 (2.7)
Grab Tensile, lb (N)	ASTM D 4632	150 (667)	205 (911)	250 (1112)
Puncture Strength, lb (N)	ASTM D 4833	85 (378)	110 (485)	150 (667)
AOS, US Sieve (mm)	ASTM D 4751	70 (0.212)	80 (0.180)	100 (0.150)
Flow Rate, gpm/ft ² (lpm/m ²)	ASTM D 4491	110 (4480)	110 (4480)	85 (3460)
UV Resistance, % retained	ASTM D 4355 (after 500 hours)	70	70	70

(a) Gradient of 1.0, normal load of 10,000 psf, water at 70° between stainless steel plates.

(b) Greater than the friction angle of the textile to soil.

(c) Component properties prior to lamination.

(d) Other geotextiles are available and may be provided as agreed upon by GSE. All geotextile property values are as reported by the geotextile supplier.

(e) These are typical values and are based on the cumulative results of specimens tested and as determined by GSE Quality Assurance practices.

Table 02621-3

Project Number:

02621-6

9/29/00

Standard Property Drainage Sheet Tri-planer					
Tested Property	Test Method	MINIMUM AVERAGE VALUES ^(f)			
		TP225-66	TP225-88	TP275-66	TP275-88
Transmissivity, m ² /sec (Note 1)	ASTM D4716-99 (15 min seating)	2.7X10 ^{-3(a)}	2.7X10 ^{-3(a)}	2.2X10 ^{-3(b)}	2.2X10 ^{-3(b)}
Ply Adhesion, lb/in (N/mm)	ASTM D 413 or F 904	1.0 (178)	1.0 (178)	1.0 (178)	1.0 (178)
Roll Width, ft (m)		6.7 (2.0)	6.7 (2.0)	6.7 (2.0)	6.7 (2.0)
Roll Length, ft (m)		200 (60.9)	200 (60.9)	200 (60.9)	200 (60.9)
Net Component Only ^(g)					
Transmissivity, m ² /sec (Note 1)	ASTM D4716-99 (15 min seating)	1.6X10 ^{-3(d)}	1.6X10 ^{-3(d)}	1.4X10 ^{-3(e)}	1.4X10 ^{-3(e)}
Thickness, mil (mm)	ASTM D 5199	225 (5.7)	225 (5.7)	275 (6.9)	275 (6.9)
Density, g/cm ³	ASTM D 1505	0.94	0.94	0.94	0.94
Tensile Strength (MD), lb/in (N/mm)	ASTM D 4595	58 (10)	58 (10)	75 (13)	75 (13)
Carbon Black Content, %	ASTM D 4218	2.0	2.0	2.0	2.0
Geotextile Component Only ^(g)					
Thickness, mil (mm)	ASTM D 5199	80 (2.0)	90 (2.2)	80 (2.0)	90 (2.2)
Grab Tensile, lb (N)	ASTM D 4632	160 (710)	205 (911)	160 (710)	205 (911)
Mass per Unit Area, oz/sy (g/m ²)	ASTM 5261	6 (200)	8 (270)	6 (200)	8 (270)
Puncture Strength, lb (N)	ASTM D 4833	85 (378)	110 (485)	85 (378)	110 (485)
AOS, US Sieve (mm)	ASTM D 4751	0.212 (70)	0.180 (80)	0.212 (70)	0.180 (80)
Flow Rate, gpm/ft ² (lpm/m ²)	ASTM D 4491	110 (4480)	110 (4480)	110 (4480)	110 (4480)
UV Resistance, % retained	ASTM D 4355 (after 500 hours)	70	70	70	70

(a) Gradient of 0.1, normal load of 10,000 psf, water at 70° with geocomposite in soil.

(b) Gradient of 0.10, normal load of 15,000 psf, water at 70° with geocomposite in soil.

(c) Greater than the friction angle of the textile to soil.

(d) Gradient of 1.0, normal load of 10,000 psf, water at 70° between membrane.

(e) Gradient of 1.0, normal load of 20,000 psf, water at 70° between membrane.

(f) These are typical values and are based on the cumulative results of specimens tested and as determined by the Manufacturer.

(g) Component properties prior to lamination.

Note 1- This is an index test, however, GSE recommends specifying long-term performance testing under site-specific conditions.

C. Resin

Project Number:

02621-7

9/29/00

1. Resin shall be new first quality, compounded polyethylene resin.
2. Natural resin (without carbon black) shall meet the following additional minimum requirements:

Table 02621-4

Property	Test Method ⁽¹⁾	Value
Density (g/cm ³)	ASTM D 1505	0.94
Melt Flow Index (g/10 min)	ASTM D 1238	≤ 1.0

¹GSE utilizes test equipment and procedures that enable effective and economical confirmation that the product will conform to specifications based on the noted procedures. Some test procedures have been modified for application to geosynthetics. All procedures and values are subject to change without prior notification.

2.02 MANUFACTURING QUALITY CONTROL

- A. The geocomposite shall be manufactured in accordance with the Manufacturer's Quality Control Plan submitted to and approved by the ENGINEER.
- B. The geocomposite shall be tested according to the test methods and frequencies listed below:

Table 02621-4

Manufacturing Quality Control Test Frequencies				
Characteristics	Test Method	Units	FREQUENCY	
			Bi-Planer	Tri-Planer
<i>Resin</i>				
Polymer Density	ASTM D 1505	g/cm ³	Once Per Lot	Once Per Lot
Melt Flow Index	ASTM D 1238	g/10 min	Once Per Lot	Once Per Lot
<i>Geonet Test</i>				
Thickness	ASTM D 5199	mil	Every 5 th Roll	40,000 ft ²
Carbon Black	ASTM D 4218	%	Every 5 th Roll	40,000 ft ²
Tensile Strength, MD	ASTM D 4595	lbs/ ft	Every 5 th Roll	40,000 ft ²
<i>Geotextile Tests</i>				
Mass per Unit Area	ASTM D 5261	oz/yd ²	Every 90,000 ft ²	Every 90,000 ft ²
Grab Tensile	ASTM D 4632	lbs.	Every 90,000 ft ²	Every 90,000 ft ²
Puncture	ASTM D 4833	lbs.	Every 90,000 ft ²	Every 90,000 ft ²
AOS, US Sieve	ASTM D 4751	mm	Every 540,000 ft ²	Every 540,000 ft ²
Water Flow Rate	ASTM D 4491	gpm/ft ²	Every 540,000 ft ²	Every 540,000 ft ²
<i>Geocomposite Tests</i>				
Ply Adhesion	GRI GC-7	lbs/ in.	Every 5 th Roll	40,000 ft ²
Transmissivity	ASTM D 4716-99	m ² /sec	Every 240 th Roll	10,000 ft ²

PART 3: EXECUTION

3.01 FAMILIARIZATION

A. Inspection

1. Prior to implementing any of the work in the Section to be lined, the INSTALLER shall carefully inspect the installed work of all other Sections and verify that all work is complete to the point where the installation of the Section may properly commence without adverse impact.
2. If the INSTALLER has any concerns regarding the installed work of other Sections, he shall notify the Project ENGINEER.

3.02 MATERIAL PLACEMENT

- A. The geocomposite roll should be installed in the direction of the slope and in the intended direction of flow unless otherwise specified by the ENGINEER.
- B. If the project contains long, steep slopes, special care should be taken so that only full length rolls are used at the top of the slope.
- C. In the presence of wind, all geocomposites shall be weighted down with sandbags or the equivalent. Such sandbags shall be used during placement and remain until replaced with cover material.
- D. If the project includes an anchor trench at the top of the slopes, the geocomposite shall be properly anchored to resist sliding. Anchor trench compacting equipment shall not come into direct contact with the geocomposite.
- E. In applying fill material, no equipment can drive directly across the geocomposite. The specified fill material shall be placed and spread utilizing vehicles with a low ground pressure.
- F. The cover soil shall be placed in the geocomposite in a manner that prevents damage to the geocomposite. Placement of the cover soil shall proceed immediately following the placement and inspection of the geocomposite.

3.03 SEAMS AND OVERLAPS

- A. Each component of the geocomposite will be secured or seamed to the like component at overlaps.
- B. Geonet Components
 1. Adjacent edges of the geonet along the length of the geocomposite roll shall be placed with the edges of each geonet butted against each other.
 2. The overlaps shall be joined by tying the geonet structure with cable ties. These ties shall be spaced every 5 feet along the roll length.

3. Adjoining geocomposite rolls (end to end) across the roll width should be shingled down in the direction of the slope, with the geonet portion of the top overlapping the geonet portion of the bottom geocomposite a minimum of 12 inches across the roll width.
4. The geonet portion should be tied every 6 inches in the anchor trench or as specified by the ENGINEER.

3.04 REPAIR

- A. Prior to covering the deployed geocomposite, each roll shall be inspected for damage resulting from construction.
- B. Any rips, tears or damaged areas on the deployed geocomposite shall be removed and patched. The patch shall be secured to the original geonet by tying every 6 inches with the approved tying devices. If the area to be repaired is more than 50 percent of the width of the panel, the damaged area shall be cut out and the two portions of the geonet shall be cut out and the two portions of the geonet shall be joined in accordance with Subsection 3.03.

END OF SECTION



GSE HyperFlex[®]
Premium Grade
HDPE Geomembrane

GSE HyperFlex is a premium grade, high density polyethylene (HDPE) geomembrane produced from specially formulated, virgin polyethylene resin. This polyethylene resin is designed specifically for flexible geomembrane applications. HyperFlex has outstanding chemical resistance, mechanical properties, environmental stress crack resistance, dimensional stability and thermal aging characteristics. HyperFlex contains approximately 97.5% polyethylene, 2.5% carbon black and trace amounts of antioxidants and heat stabilizers; no other additives, fillers or extenders are used. HyperFlex has outstanding resistance to UV radiation and stress cracking and is therefore well suited for exposed applications.

TESTED PROPERTY	TEST METHOD	MINIMUM VALUES			
Thickness, mils (mm)	ASTM D 5199	54 (1.4)	72 (1.8)	90 (2.3)	108 (2.7)
Density, g/cm ³	ASTM D 1505	0.94	0.94	0.94	0.94
Tensile Properties (each direction)	ASTM D 638, Type IV				
Strength at Break, lb/in-width (N/mm)	Dumbell, 2 ipm	243 (43)	324 (57)	405 (71)	486 (85)
Strength at Yield, lb/in-width (N/mm)		130 (23)	173 (30)	216 (38)	259 (45)
Elongation at Break, %	G.L. = 2.0 in (51 mm)	700	700	700	700
Elongation at Yield, %	G.L. = 1.3 in (33 mm)	13	13	13	13
Tear Resistance, lb (N)	ASTM D 1004	42 (187)	56 (249)	70 (311)	84 (373)
Puncture Resistance, lb (N)	ASTM D 4833	119 (530)	158 (703)	198 (881)	238 (1060)
Carbon Black Content, %	ASTM D 1603	2.0	2.0	2.0	2.0
Carbon Black Dispersion	ASTM D 5596	+Note 1	+Note 1	+Note 1	+Note 1
Notched Constant Tensile Load, hrs	ASTM D 5397, Appendix	400	400	400	400

REFERENCE PROPERTY	TEST METHOD	NOMINAL VALUES			
Thickness, mils (mm)	ASTM D 5199	60 (1.5)	80 (2.0)	100 (2.5)	120 (3.0)
Roll Length (approximate), ft (m)		470 (143)	350 (107)	285 (85)	200 (61)
Low Temperature Brittleness, °F (°C)	ASTM D 746, Cond. B	<-107 (<-77)	<-107 (<-77)	<-107 (<-77)	<-107 (<-77)
Oxidative Induction Time, minutes	ASTM D 3895, 200 °C; O ₂ , 1 atm>100	>100	>100	>100	
Water Absorption, % wt. change	ASTM D 570	<0.01	<0.01	<0.01	<0.01
Moisture Vapor Transmission, g/m ² day	ASTM E 96	<0.001	<0.001	<0.001	<0.001
Dimensional Stability (each direction), %	ASTM D 1204, 100 °C, 1 hr	±2	±2	±2	±2

+Note 1: Dispersion only applies to near spherical agglomerates. 9 of 10 views shall be Category 1 or 2. No more than 1 view from Category 3.

This information is provided for reference purposes only and is not intended as a warranty or guarantee. GSE assumes no liability in connection with the use of this information. Check with GSE for current, standard minimum quality assurance procedures.

* GSE and other marks used in this document are trademarks and service marks of GSE Lining Technology, Inc.; certain of which are registered in the United States and other

Americas
GSE Lining Technology, Inc.
19103 Gundie Road
Houston, TX 77073
U.S.A.
Phone: 281-443-8564
800-435-2008
Fax: 281-230-8650

Europe/Africa
GSE Lining Technology GmbH
Buxtehuder Strasse 112
D-21037 Hamburg
Germany
Phone: 49-40767420
Fax: 49-40-7674233

Asia/Pacific
GSE Lining Technology Company Ltd.
RASA Tower 555, 26th Floor
Phaholyothin Road, Ladyao Chatuchak
Bangkok 10900
Thailand
Phone: 66-2-937-0091
Fax: 66-2-937-0097

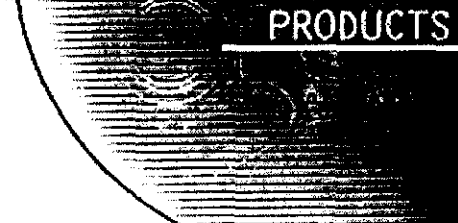
Represented by:

For environmental lining solutions...the world comes to GSE.[®]
A Gundie/SLT Environmental, Inc. Company

www.gseworld.com

DS 001 R01/10/01

GSE US OPERATIONS		Employment Corporate Home Industry Links Search Contact Us					
PRODUCTS	INSTALLATION SERVICES	FABRICATION	QA/QC	APPLICATIONS	DEALER LOCATIONS	LOCATIONS	DROP-IN SPECIFICATIONS



PRODUCTS

- ▶ DATA SHEET (ENGLISH - PDF) (SPANISH - PDF)
- ▶ PRODUCT QA/QC
- ▶ BIBLIOGRAPHY
- ▶ FAQ
- ▶ E-MAIL FOR MATERIAL

GSE HyperFlex

Typical Questions and Answers

Q:

A: GSE HyperFlex is a smooth, premium grade, high density polyethylene (HDPE) geomembrane liner. It is made with resins specifically designed for geomembrane production.

Q:

A: HDPE liners have a proven history of success in almost every geomembrane application. HDPE's combination of physical properties, chemical resistance and long term performance exceed the capabilities of any other material. All GSE HDPE geomembrane materials meet or exceed the material property requirements of GRI GM-13. The US EPA, local, state and federal regulatory bodies have recommended the use of HDPE geomembranes for a broad variety of containment applications. HDPE is the material of choice for applications requiring durability.

Q:

A: Undersea telephone cables, gas transmission pipelines, agriculture and household chemicals containers, low level radioactive waste disposal drums and hazardous waste containment.

Q:

A: GSE HyperFlex is typically used for applications requiring maximum strength and long term exposed performance. GSE UltraFlex is a more flexible geomembrane designed for use in applications where differential settlement is a concern and multiaxial properties and high elongation values are most important.

Q:

A: GSE HyperFlex FR is a flame retardant geomembrane designed for use in nuclear facilities, oil and petrochemical applications and other areas and applications where flame retardant materials are required. Contact your authorized GSE representative for additional information on product selection.

Q: *How long would GSE HyperFlex last in a landfill application?*

A: GSE HyperFlex has demonstrated long term performance in geomembrane applications such as landfill liners and caps, mining, potable water containment, hazardous waste containment, sewage treatment, agricultural applications and others.

Q:

A: GSE HyperFlex has an extensive proven record as the premier HDPE material available with thousands of successful installations. GSE HyperFlex is produced with specially formulated resins designed to provide superior performance in physical properties, resistance to stress-cracking and long term performance, in both exposed and buried applications.

Q:

A: GSE HyperFlex can be easily and simply welded utilizing standard fusion or extrusion welding equipment and technologies. No extra preparation of the liner is required; optimum welding conditions will vary.

Q:

A: The welding rod is made from the same high quality raw materials as the membrane itself.

Q:

A: To detect the presence of holes in the liner all of GSE's production lines utilize an electronic spark (hole) detection system. Every square inch of liner must pass through the spark detection device before it is wound onto a roll and submitted to the GSE lab for final approval.

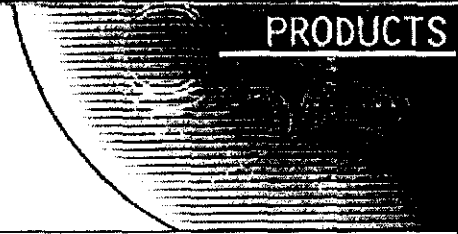
Q:

A: Rolls should be stored on a firm, smooth surface free of large and sharp stones. GSE's geomembrane materials are UV stabilized and require no special protection from moisture and sunlight. Rolls of liner should always be handled by using the attached carrying straps with adequately sized equipment. The carrying straps should be inspected before handling to ensure no wear or damage to the straps. Handling rolls by forklift may damage the material.

Q:

A: GSE usually ships rolls to the job site via flatbed truck. Containerized packaging for export orders, roll shipment via rail and several other shipping options can be used.

GSE US OPERATIONS		Employment	Corporate Home	Industry Links	Search	Contact Us
PRODUCTS	INSTALLATION SERVICES	FABRICATION	QA/QC	APPLICATIONS	DEALER LOCATIONS	LOCATIONS
						DROP-IN SPECIFICATIONS



PRODUCTS

- ▶ DATA SHEET (ENGLISH - PDF) (SPANISH - PDF)
- ▶ PRODUCT QA/QC
- ▶ BIBLIOGRAPHY
- ▶ FAQ
- ▶ E-MAIL FOR MATERIAL

GSE HyperFlex

BIBLIOGRAPHY

- (1993) Tisinger, L.G., and Giroud, J.P., "The Durability of HDPE Geomembranes", Geotechnical Fabrics Report, September 1993.
- (1982) Walker, M.D. and Juzkow, M.W., "The Twenty Year Weathering of Polyethylene Compounds Containing Carbon Black", Proceedings of the Society of Plastics Engineers ANTEC Conference.
- (1984) Chan, M.G., Gilroy, H.M., Martin, W.M., "Long Term Aging Properties of Polyolefins", Proceedings of the Society of Plastics Engineers Regional Technical Conference: Polyolefins 4, Houston, TX, pages 12-17.
- (1994) Adams, M.W., "NCTL Testing of HyperFlex", Internal GSE publication, Houston, TX, (TP-216).
- (1994) Haddad, A.N. and Gunning, R.T., "Carbon Black and Stabilizers for Geosynthetics", Proceedings of the GRI-8 Conference on Geosynthetic Resins, Formulations and Manufacturing, Philadelphia, PA, pages 61-73.
- (1997) Gualtieri, C. and Rotondo, G., "Comparison of the Performance of Two Different Geomembranes for Sanitary Landfill", Proceedings Sardinia 97, Sixth International Landfill Symposium, Cagliari, Italy, pages 197-206.
- (1993) Yim, G. and Godin, M., "Long-term Heat Aging Stabilization Study of Polyethylene and its Relationship with Oxidative Induction Time (OIT)", Proceedings of Geosynthetics 1993, Vancouver, Canada, pages 803-815.
- (1997) Guglielmetti, J.L. et. al., "Geomembrane Installation and Construction Survivability", Proceedings of Geosynthetics 1997, Long Beach, California, pages 235-251.

[| Employment](#) | [Corporate](#) | [Home](#) | [Industry Links](#) | [Search](#) | [Contact Us](#) |
| [Products](#) | [Installation Services](#) | [Fabrication](#) | [QA/QC](#) | [Applications](#) | [Dealer Locations](#) | [Locations](#) | [Drop-In Specifications](#) |
| [Datasheet](#) | [Technical Manual](#) | [Product QA/QC](#) | [Bibliography](#) | [FAQ](#) | [Material Request Form](#) |

ATTACHMENT 6

SUPPORTIVE LITERATURE ON THE DURABILITY OF HDPE LINERS

The durability of HDPE geomembranes

By L.G. Tisinger and J.P. Giroud

Excellent papers have been written on the durability of high density polyethylene (HDPE) geomembranes. Since the subject is very complex, however, many of these papers can be understood only by polymer scientists. Because information on the durability of HDPE geomembranes is very important, such information needs to be presented to the wide range of geomembrane users.

In this article, aspects of materials' durability that relate to the composition and/or structure of the material used in the geomembrane will be discussed. Mechanical actions, including stress cracking, and aspects related to the durability of the geomembrane seams will not be addressed.

From low to high density

Polyethylene is a polymer. A polymer is a molecule that has many units (from the Greek, *poly*, which means many, and *meros*, which means part). In contrast, a monomer is a single unit (from the Greek *monos*, which means single). Polymers are made from monomers through a reaction called polymerization.

For example, a polyethylene polymer results from the polymerization reaction of the ethylene monomer (Seymour and Carraher, 1981).

Production of polyethylene began in the mid-1930s from a process using high pressure and high temperature (Brydson, 1982). In the mid 1950s, new reaction conditions were introduced in which polyethylene was produced at lower pressures and lower temperatures than before.

As a result, a new variety of polyethylene was made that had a higher softening point, a higher density and more rigidity than earlier types.

This new variety of polyethylene was appropriately named high density polyethylene, while the name low density

polyethylene (LDPE) became used to designate the type of polyethylene produced with the early process.

Anatomy of HDPE

The high density of HDPE results from the presence of many crystals of polyethylene molecules within its structure. Crystals are regions in which matter is ordered and densely packed.

The crystalline regions are connected by less organized, or amorphous regions, hence the terminology semicrystalline structure. The amount of crystalline regions in a material is typically expressed as crystallinity, a ratio that varies between 0 percent for a totally amorphous material and 100 percent for a totally crystalline material. Crystallinity, measured by differential scanning calimetry, is the ratio of the energy required to melt a given HDPE to the energy required to melt a totally crystalline HDPE.

Because they are composed of densely packed matter, crystals are essentially impermeable to liquids and chemicals. Clearly, a relationship exists between the number of crystals, the density of polyethylene and the impermeability of the geomembrane.

HDPE used to produce geomembranes is made not only from ethylene. It also contains some comonomer (a monomer in addition to ethylene at a proportion of approximately 1 percent to 3 percent), such as butene, hexene or octene. Comonomers result in more branching on the polyethylene molecules of HDPE, which usually improves HDPE materials' flexibility and environmental stress cracking resistance (Bourgeois and Blackett, 1990).

As more branching slightly increases the distance between parallel long-chain molecules, however, it increases HDPE material permeability and reduces its chemical resistance, but by amounts that are generally considered insignificant.

HDPE geomembranes are not made

from HDPE only. They also contain additives, such as carbon black and antioxidants. The resulting material is called the HDPE compound and it contains approximately 97 percent HDPE, 2.5 percent carbon black, and 0.5 percent antioxidants. Note that HDPE geomembranes do not contain plasticizers.

Chemical reactions

HDPE is chemically resistant for two reasons. First, as all members of the polyethylene family, HDPE is essentially inert. Second, as discussed earlier, because of its high density, HDPE has a low permeability; therefore, it resists penetration by chemicals. Under certain conditions, however, HDPE can react with chemicals. A chemical reaction between a material and a chemical occurs when the chemical modifies the structure of the molecules making up the material.

Reaction of HDPE with chemicals is generally limited to oxidizing agents, such as nitric acid and oxygen. In other words, oxidation is the predominant mechanism of chemical reaction of HDPE. Oxidation is a step-wise process.

The polymer first absorbs energy, provided by heat, UV radiation and/or high-energy radiation (radioactivity). This absorption excites the polymer molecules, causing them to break, forming highly reactive fragments referred to as radicals. This mechanism is called chain scission. The radicals then react with oxygen, forming even more radicals.

As the process proceeds, an increasing number of radicals are formed. The process is terminated only when the radicals either react with antioxidants or recombine, or when energy is no longer supplied (Brydson, 1982; Rodriguez, 1970; and Seymour and Carraher, 1981). If oxidation occurs, it causes the molecular weight of molecules to decrease, making the HDPE material soften and embrittle, thereby becoming subject to stress crack-

ing. Oxidation occurs only if two conditions are present.

The first condition is a high concentration of the oxidizing agent. The second condition is that the material must receive a sufficient supply of energy to activate the reaction.

When the conditions are not present—which is often the case—HDPE is not attacked. This is confirmed by reported cases of EPA 9090 tests conducted to evaluate the chemical compatibility between HDPE geomembranes and municipal waste or hazardous waste leachates from modern waste disposal facilities, which indicate no detectable deterioration of the properties of HDPE geomembranes (Ojeshima et al., 1984; and Dudzik and Tisinger, 1990).

Physical interaction

Another potential mechanism of HDPE degradation is physical interaction. Physical interaction of HDPE with a chemical occurs when HDPE, without experiencing change in the structure of its molecules, absorbs the chemical, usually organic. Organic chemicals can interact with HDPE, because like HDPE, they are nonpolar, and therefore, have similar intermolecular forces (cohesive forces) holding adjacent molecules together. The most typical mechanism of physical interaction involving HDPE is solvation.

Solvation Solvation is a physical process by which solvent molecules are absorbed into a material. Solvation causes a polymeric material to swell (which increases its permeability) and to soften, a process often referred to as plasticization. A limited degree of swelling and softening is, to some extent, reversible: The geomembrane more or less retrieves its original dimensions and properties if the solvent is removed by evaporation. The ultimate degree of solvation is dissolution, where the molecules of the initially solid material are dispersed in the solvent. Of course, this mechanism is not reversible.

Typical solvents that may cause solvation of HDPE are aromatic solvents, such as benzene, toluene, xylene and halogenated solvents, such as chloroform, methylene chloride and trichloroethylene. These solvents cause some degree of solvation of HDPE at ordinary temperature. Dissolution of HDPE by these solvents,

A USEPA ad hoc committee has concluded that polymeric landfill lining materials should maintain their integrity in waste disposal environments in "terms of hundreds of years."

however, will not occur at ambient temperature.

In fact, no known solvents can dissolve HDPE at room temperature. Typical waste disposal facility temperatures should not exceed 50 C, which is significantly below 80 C, the temperature at which some solvents may begin to dissolve HDPE. These solvents should, therefore, not cause complete dissolution of HDPE geomembranes under waste disposal facility conditions.

Moreover, the solvents must be present at very high concentration to affect HDPE, a condition that is not observed in waste disposal facilities.

Extraction Extraction is a mechanism of physical interaction between polymeric compounds and chemicals. It is a process by which chemicals and heat cause additives, such as plasticizers and antioxidants, to leach out of the polymeric compounds.

HDPE compounds used to produce geomembranes do not contain plasticizers; however, their antioxidants can be extracted. Such an extraction typically requires a very high concentration of chemical, a condition typically not present in a waste disposal facility. Moreover, most modern antioxidants have a high molecular weight and are physically entangled among the polyethylene molecules. Such physical entanglement greatly reduces the ability of chemicals to extract antioxidants. As a result, HDPE geomembranes do not undergo significant loss of antioxidants by extraction.

Energy and environment

In all the potential mechanisms of degradation described above, energy plays a crucial role. In geomembrane applications, the most typical sources of energy are heat and ultraviolet (UV) radi-

ation; both conditions often occur through direct exposure to sunlight. Also, exposure to high-energy radiation (radioactivity) can induce reaction of HDPE with oxidizing agents. High-energy radiation also may cause HDPE to crosslink, that is, to form chemical bonds between adjacent polyethylene molecules. As a result, HDPE may harden and become brittle. Again, for this to happen, HDPE would have to be exposed to large doses of high-energy radiation (Whyatt and Farnsworth, 1990).

In the absence of either oxygen or energy, oxidation, the predominant mechanism of chemical reaction of HDPE, cannot occur. Typical waste disposal facility environments are anaerobic, eliminating the possibility for oxidative degradation of HDPE geomembranes once they are buried (Haxo and Haxo, 1989).

In addition, the supply of energy is limited, because there is no light and because geomembranes are usually protected by a layer of soil, which insulates them from heat generated by decomposition of waste.

Some oxidation of HDPE geomembranes can occur as the result of their exposure to sun during installation. Such oxidation is limited and superficial, however, because carbon black, which is an additive used in most HDPE geomembranes, absorbs sunlight, preventing it from penetrating the geomembrane (Whitney, 1988).

Furthermore, the effects of oxidation should be limited, because HDPE geomembranes contain antioxidants, additives that stabilize radicals generated by HDPE's absorption of energy. Information on the durability of HDPE geomembranes that are permanently exposed can be obtained from experience gained in observing the performance of existing facilities.

If not attacked, could HDPE simply age?

Aging refers to changes that occur in materials when they are subjected to the type of temperate conditions in which a human could survive (but would age)—no contact with liquid chemicals, moderate ambient temperature, no exposure to UV radiation or radioactivity, no supply of oxygen beyond that naturally present in air, etc. Studies have indicated

that the effect of such conditions on HDPE materials is very slow.

For example, test results obtained from polyethylene films stored in a ventilated box exposed to desert, temperate and tropical environments for 15 years, have shown negligible changes in crystallinity and minimal evidence of oxidation (Moakes, 1976).

Resistance to aging is best evaluated by observations of actual performance in service. Polyethylene has a long track record of successful uses. Polyethylene was first synthesized in 1933, and became commercially available in 1937.

The use of polyethylene for cable sheathing began in 1942 (Gilroy, 1985). Since then, polyethylene has been the material of choice for the protection of transatlantic cables.

The first HDPE geomembranes were used in 1973 in Europe (Knipschild, 1984) and in 1974 in the United States. To date, HDPE geomembranes have been used, exposed or buried, for 20 years.

Wherever they have been properly protected against mechanical failures (including stress cracking), HDPE geomembranes have performed satisfactorily. The performance of HDPE geomembranes for 20 years confirms the successful performance of HDPE in other outdoor applications, such as cable sheathing and buried pipes, for more than 40 years.

How long will geomembranes last?

A question frequently asked about geosynthetics and geomembranes in particular is, "How long will they last?" To answer this question, some clear conclusions can be drawn from the facts presented earlier.

Experience has shown that exposed HDPE materials, including geomembranes, can perform satisfactorily for decades if they are protected from mechanical aggressions.

In waste disposal facility environ-

ments, once HDPE geomembranes are buried, only little energy should be acting on them, and in addition, the supply of oxygen should most likely be very low. In the absence of an aggressive environment, therefore, HDPE geomembranes should last for a very long time in waste disposal facilities.

A U. S. Environmental Protection Agency (USEPA) ad hoc committee on the durability of polymeric landfill lining materials has concluded that the polymeric landfill lining materials should maintain their integrity in waste disposal facility environments in "terms of hundreds of years" (Haxo and Haxo 1988). This conclusion is consistent with durability evaluations made using the Arrhenius model (Koerner et al., 1990). One can conclude, then, that in properly designed and constructed facilities, HDPE geomembranes should be able to protect ground water from leachate for hundreds of years, which is long after leachate generation has stopped.

The durability of HDPE geomembranes

References

- Bourgeois, J.R. and Blackett P.W., "HMW High Density Polyethylene," *Modern Plastics Encyclopedia*, McGraw-Hill, New Jersey, October 1990, pp. 75-76
- Brydson, J.A., "Plastics Materials," Butterworth's Scientific, Boston, 1982, 800 pages
- Dudzic, B.E. and Tisinger, L.G., "An Evaluation of Chemical Compatibility Test Results of High Density Polyethylene Exposed to Industrial Waste Leachate," *Geosynthetic Testing For Waste Containment Applications*, ASTM STP 1081, Robert M. Koerner, editor, American Society for Testing and Materials, Philadelphia, 1990, pp. 37-56
- Gilroy, H.M., "Polyolefin Longevity For Telephone Service," *Auzec*, 1985, pp. 258-264
- Haxo, H.E. and Haxo, P.D., "Consensus Report of the Ad Hoc Meeting on the Service Life in Landfill Environments of Flexible Membrane Liners and Other Synthetic Polymeric Materials of Construction," *Mastec Inc.*, Alameda, Calif., Report # M86-155, May 1988, 55 pages
- Haxo, H.E. and Haxo, P.D., "Environmental Conditions Encountered by Geosynthetics in Containment Facilities," "Durability and Aging of Geosynthetics," Robert M. Koerner, editor, Elsevier, New York, 1989, pp. 23-47
- Knipschild, F.W., "Guidelines for the Installation of Geomembranes for Groundwater Protection in West Germany," *Proceedings of the International Conference on Geomembranes*, Vol. 1, Denver, Colo., June 1984, pp. 227-231

- Koerner, R.M., Lord, A.E. and Hsuan, Y.H., "Long-Term Durability and Aging of Geomembranes," "Waste Containment Systems: Construction, Regulation, and Performance," Bonaparte, R., ASCE Geotechnical Special Publication No. 26, Proceedings of a symposium held in San Francisco, Calif., November 1990, pp. 52-83
- Moakes, R.C., "Long-Term Natural Aging," *Rapra Members Journal*, March/April 1976, pp. 19-22
- Ojeshima, A., Jett, M.E. and Kneic, R., "An Assessment of HDPE Liner Durability: A Report on Selected Installations," *International Conference on Geomembranes*, Denver, 1984, Session 3C: Durability, pp. 317-320
- Rodriguez, F., "Principles of Polymer Systems," McGraw Hill, New York, 1970, 560 pages
- Seymour, R.B. and Carraher, C.E., "Polymer Chemistry: An Introduction," Dekker, New York, 1981, 564 pages
- Whyatt, G.A. and Farnsworth, R.K., "The High Ph and Chemical Radiation Compatibility of Various Liner Materials," *Geosynthetic Testing for Waste Containment Applications*, ASTM STP 1081, Robert M. Koerner, editor, American Society for Testing and Materials, Philadelphia, 1990, pp. 110-124
- Whitney, L.C., "Specifying Carbon Blacks for UV Light Protection," *Plastics Engineering*, December 1982, pp. 29-33

Acknowledgements

The authors acknowledge the technical assistance of J.F. Beech, F. Struve and C.E. Carraher in the preparation of this article.



TECHNICAL NOTE

*For environmental lining solutions...the world comes to GSE.**

UV Resistance of GSE Polyethylene Geomembranes

Weathering of geomembrane lining materials continue to be a major interest to those seeking long term protection against ultraviolet exposure. In general, weathering and other environmental effects which cause lasting material changes are classified as aging. Changes in a material can be determined by studying the changes in material's mechanical properties. Under certain conditions, a change in mechanical characteristics can permit an estimation of the material's life span.

GSE polyethylene geomembranes are manufactured from first quality polyethylene resins¹. To combat causes of aging, such as ultraviolet exposure, properly selected and dispersed carbon black is added to GSE geomembranes at 2% to 3%. Carbon black is universally accepted as being resistant to significant deterioration caused by weathering for 50 years or more. In fact, AT&T Bell Laboratories (Polyolefin Longevity for Telephone Service, H.M. Gilroy, AT&T Bell Laboratories, ANTEC, '85) set out many years ago to demonstrate that the resistance to ultraviolet exposure and weathering for polyethylene is in excess of 45 years².

In addition to a high quality carbon black, GSE utilizes a highly effective chemical UV stabilizers which further extend the life of the material to which it is added. These additives absorb incident radiation and or terminate free radical production, thus protecting the polyethylene against thermal degradation and possible chemical reactions with surrounding materials. Polyethylene resins, chemical stabilization components and carbon black dispersions have all been improved as a result of the industry testing. As a result, properly formulated and compounded polyethylenes have an estimated projected life in excess of 100 years for resistance to weathering.

Not only is the quality of additive packages important, but the integrity of the polyethylene resin itself plays a vital roll in UV resistance. There are various properties of the resin package which can be adjusted to improve the UV resistance of a material. It has

been determined that reducing the density of the polyethylene base resin reduces both the weathering and chemical resistance of the resin and the effectiveness of chemical stabilizers and carbon black. It is GSE's current opinion that polyethylene resins below a density of about 0.915 g/cc are undesirable for use where dependable long-term weathering or chemical resistance is required.

There are, however, other factors which effect the potential UV resistance of a material and thus any lifetime predictions determined in a laboratory. Some items which effect or cause variation in the resistance of a material to UV degradation are:

- average density
- molecular weight distribution
- average molecular weight
- carbon black type, content and dispersion
- density range or distribution
- chemical stabilizer system
- catalyst type and amount of residue
- copolymer type
- combined chemical exposures
- failure criteria

Essentially all liquid containment applications leave some portion of the slope liner exposed to weathering. Therefore proper resin and additive formulations are very important to enhance the material's resistance to UV degradation.

¹ GSE Technical Note TN011, *GSE Lining Technology*, Houston, Texas, 1999.

² Gilroy, H.M., "Polyolefin Longevity for Telephone service", AT&T Bell Laboratories, ANTEC, 1985.

This information is provided for reference purposes only and is not intended as a warranty or guarantee. GSE assumes no liability in connection with the use of this information. Check with GSE for current, standard minimum quality assurance procedures.

** GSE and other marks used in this document are trademarks and service marks of GSE Lining Technology, Inc., certain of which are registered in the United States and other countries.*

Americas
GSE Lining Technology, Inc.
19103 Gundale Road
Houston, TX 77073
U.S.A.
Phone: 281-443-8564
800-435-2008
Fax: 281-230-8650

Europe/Africa
GSE Lining Technology GmbH
Buechelstrasse 112
D-21037 Hamburg
Germany
Phone: 49-40767420
Fax: 49-40-7674233

Asia/Pacific
GSE Lining Technology Company Ltd.
RASA Tower 555, 26th Floor
Phaholyothin Road, Lodym Chetuchak
Bangkok 10900
Thailand
Phone: 66-2-937-0091
Fax: 66-2-937-0097

Represented by:

*For environmental lining solutions...the world comes to GSE**

A Gundale/KIT Environmental Inc. Company